DELTA ECOSYSTEM WHITE PAPER

Prepared for consideration by the Delta Stewardship Council

October 18, 2010

Not reviewed or approved by the Delta Stewardship Council

Send comments to deltaplancomment@deltacouncil.ca.gov.

All comments received are posted to the Delta Stewardship Council web site: http://www.deltacouncil.ca.gov/

Executive Summary

The Delta and Suisun Marsh ecosystem, as a large component of the San Francisco Estuary, was once one of the most biologically productive and diverse ecosystems on the west coast, supporting a wide array of native plant and wildlife species and providing important habitat for many migratory species. The Delta ecosystem is now in peril. As a result of human activity to reclaim farmland, protect areas from flood, and provide water for agriculture and communities; discharge of wastes from agriculture, industry, and urban areas; and the introduction of harmful invasive species, the Delta has been modified in ways that adversely influence ecosystem function and compromise its ability to support a healthy ecosystem. These changes not only affect the species that live there, but also the ecosystem services that benefit humans, such as improved water quality, agricultural productivity, healthy commercial and sport fisheries, flood protection, and recreation. The Delta ecosystem is now on a trajectory of change that cannot be completely reversed but can, at best, only be managed. Actions taken from this point forward will contribute to defining the future Delta and the health of its ecosystem. Suisun Marsh, dominated by diked managed wetlands, serves a greatly increased role in supporting waterfowl on the Pacific Flyway as wetlands that formerly existed throughout the Central Valley have been long lost to agriculture. But like the Delta, Suisun Marsh is at risk from future changes, especially sea level rise, and at the same time it is very well suited to support tidal restoration efforts.

The adverse ecological effects of human activities over the past 150 years are manifested in several key environmental "indicators" – factors that can be measured today, such as declining populations of native species including many listed as threatened or endangered, low ecosystem productivity, low variability in a wide variety of important ecosystem attributes, very little natural habitat and poor connectivity amongst remaining habitats, river and slough corridors for migratory fish laden with hazards to their survival, and poor water quality including listed impaired water bodies throughout the region for numerous contaminants. The poor condition across the range of these indicators is due to the complex interactions of several environmental "stressors" – processes and mechanisms that directly influence ecosystem functions and individual species – brought about by human activities over the past 150 years. These stressors include habitat loss, major alterations in river flows, highly altered flow regimes within the Delta, very low variability in salinity and other water quality parameters, contaminant uptake, and many more. Table ES-1 illustrates the relationship between the major categories of human modifications and the consequent stressors, and Table ES-2 relates how these stressors affect the ecosystem indicators.

Table ES-1
Human Modifications Have Created Stressors that Drive Poor Ecosystem Function in the Delta

Human Modifications	**Affected Stressors Driving Poor Ecosystem Function**										
	Physical habitat loss	Flow-related habitat loss	Connectivity and interface loss	Harmful invasive species	Altered flow regimes	Altered Delta geometry	Altered sediment supply	Low residence time variability	Low salinity variability	Entrainment	Contaminant and nutrient loading
1) Wetland and floodplain reclamation	✓	✓	✓	✓	✓	✓		✓	✓		
2) Dams		✓	✓	✓	✓		✓	✓	✓		
3) Channel widening, deepening, straightening for flood control and navigation	✓	✓	✓	✓	✓	✓	✓	✓	✓		
4) Hydraulic mining debris loading	✓					✓	✓				✓
5) Upstream diversions		✓		✓	✓			✓	✓	✓	
6) In-Delta diversions		✓		✓	✓	✓		✓	✓	✓	
7) Delta exports		✓		✓	✓	✓	✓	✓	✓	✓	✓
8) Channel reconfiguration for conveyance and navigation	✓	✓	✓	✓	✓	✓	✓	✓	✓		
9) Discharges from agriculture, wastewater, industry				✓			✓				✓
10) Species introductions for recreation, biological control, accidental	✓		✓	✓			✓				✓

Table ES-2
Ecosystem Stressors Result in Measurable Indicators of Poor Ecosystem Function

Indicators of Poor Ecosystem Function	Stressors Driving Poor Ecosystem Function										
	Physical habitat loss	Flow-related habitat loss	Connectivity and interface loss	Harmful invasive species	Altered flow regimes	Altered Delta geometry	Altered sediment supply	Low residence time variability	Low salinity variability	Entrainment	Contaminant and nutrient loading
1) Population decline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2) Impaired food web productivity and dynamics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3) Low variability in the aquatic environment	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
4) Minimal and uniform habitats and poor connectivity	✓	✓	✓	✓	✓	✓	✓	✓	✓		
5) Poor transit corridor for migratory fish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6) Poor water quality	✓	✓	✓		✓	✓	✓	✓	✓		✓

The numerous regulations, policies, programs, and plans that are currently in place to improve the condition of the ecosystem or stem the decline of individual species may influence the direction of future restoration. Each of these efforts is generally in response to specific actions intended to mitigate or avoid the impacts of activities that could adversely affect the Delta ecosystem or the imperiled species it supports. Collectively, these efforts contribute to improving the Delta ecosystem, but they are generally not well coordinated and responsibility for their implementation is broadly held by numerous entities. This collection of regulations, policies, programs, and plans, particularly existing conservation plans, biological opinions, and policies that have wide-reaching influence on ecosystem management in the Delta, may constrain or influence future decisions.

The health of the Delta ecosystem is currently challenged by a variety of factors that diminish its ability to function and provide services that benefit the species it supports and humans. Many of the same factors that currently adversely affect ecosystem health and stress Delta species will continue to influence or exert pressure on the system, as will new changes in the future. Some of these factors include:

- Diversions, exports and conveyance
- Population growth and private lands
- Climate change – sea level rise, temperature, climate variability, and storm frequency and intensity
- New species invasions
- Levee integrity (seismicity, maintenance, hydrostatic pressure)
- Subsidence
- Flooded Delta islands
- SWRCB and DFG flow recommendations

Contents

Section **Page**

Tables

Figures

Section 1
Introduction

In November 2009, the California Legislature enacted SBX7 1 (Act), one of several bills passed at this time related to water supply reliability, ecosystem health, and the Delta. The Act became effective on February 3, 2010.

In the Act, the Legislature declared that the Sacramento-San Joaquin Delta (Delta) is a critically important natural resource for California and the nation. It serves Californians concurrently as both the hub of the California water system and the most valuable estuary and wetland ecosystem on the west coast of North and South America. The Legislature also declared that the Delta watershed and California's water infrastructure are in crisis and existing Delta policies are not sustainable, and that resolution of the crisis requires fundamental reorganization of the state's management of Delta watershed resources. In response to the Delta crisis, the Legislature and the Governor required development of a new long-term strategic vision for managing the Delta. Leading up to passage of the Act, the Governor appointed a Blue Ribbon Task Force to develop a Delta Vision Strategic Plan (Strategic Plan). The Strategic Plan, submitted to the Governor and the Legislature on January 3, 2009, identified that the Delta conditions were declining due to:

- Degradation of water resources, water quality, and ecosystem conditions in the Delta;
- Risks related to catastrophic failure of levees due to earthquakes, floods, sea level rise, and land subsidence; and
- Potential increased risks due to recent residential development in the Delta that could further degrade water resources, water quality, and ecosystem resources and increase risks to human life.

These issues were considered by the Legislature in identification of the following basic goals of the state for the Delta:

- Achieve the two coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place.
- Protect, maintain, and, where possible, enhance and restore the overall quality of the Delta environment, including, but not limited to, agriculture, wildlife habitat, and recreational activities.
- Ensure orderly, balanced conservation and development of Delta land resources.

- Improve flood protection by structural and nonstructural means to ensure an increased level of public health and safety.

The Legislature required development of the Delta Plan to meet the coequal goals and all of the inherent subgoals defined by statute to define an integrated and legally enforceable set of policies, strategies, and actions that will serve as a basis for future findings of consistency by state and local agencies with regard to their Delta-related projects, and for subsequent evaluation of those findings by the Council on appeal, as provided in statute and Council regulation.

As an initial step in the development of the Delta Plan, white papers are being developed to summarize:

- Historical activities that have contributed to existing conditions and current uses of Delta resources;
- Current conditions related to uses of Delta resources;
- Jurisdictional responsibilities, including overlapping authorizations; and
- Future issues related to Delta resources.

The white papers are not intended to describe the existing and projected conditions in detail. The more detailed discussions of existing and projected conditions will be presented in the Delta Plan Environmental Impact Report (DEIR). Draft versions of the DEIR chapters related to the existing and projected future conditions without implementation of the Act will be provided in early 2011 for review by the Delta Stewardship Council (Council) and the public.

Purpose and Use

Formed by the confluence of the state's two longest rivers—the Sacramento and the San Joaquin—the Delta is one of the most valuable and unique natural resources in the state and nation. Over the past 150 years, demands for water and land resources have become more competitive between ecosystem resources, agricultural users, municipal and industrial users, power generators, flood management operations in the watershed, and salmon fishing operations along the Pacific Coast. Despite the Delta's importance, the challenges of effectively addressing water resources, water quality, and other competing Delta beneficial uses have led to increased conflicts over time.

The purpose of this white paper is to address several central questions to the Delta Plan:

1. Why should we care about the Delta ecosystem (i.e., functions important to society)?
2. What tells us the Delta ecosystem is in poor condition today (i.e., indicators)?
3. What actions have caused degradation to the Delta ecosystem (i.e., human modifications to the system)?
4. What are the mechanisms through which these human modifications cause the degradation (i.e., the consequent stressors)?
5. What are the roles of current programs, plans, and policies that may influence the development of the Delta Plan?
6. Where are the available funding resources that may support ecosystem restoration activities?
7. What risks does the Delta ecosystem face in the future?

Most of the information in this white paper is summarized or taken directly from existing documents. This white paper does not address methods to reduce the risks or reduce existing or potential adverse conditions in the Delta. This white paper will be considered in the development of the framework for the Delta Plan and alternatives in the DEIR.

Statutory Requirements

The Council's statutory authority and direction relative to the Delta ecosystem are contained in the objectives identified in the Act (Section 85020 of the Water Code), which states that the policy of the State of California is to achieve the following objectives that the Legislature declares are inherent in the coequal goals for management of the Delta:

a. Manage the Delta's water and environmental resources and the water resources of the state over the long term.

b. Protect and enhance the unique cultural, recreational, and agricultural values of the California Delta as an evolving place.

c. Restore the Delta ecosystem, including its fisheries and wildlife, as the heart of a healthy estuary and wetland ecosystem.

d. Promote statewide water conservation, water use efficiency, and sustainable water use.

e. Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta.

f. Improve the water conveyance system and expand statewide water storage.

g. Reduce risks to people, property, and state interests in the Delta by effective emergency preparedness, appropriate land uses, and investments in flood protection.

h. Establish a new governance structure with the authority, responsibility, accountability, scientific support, and adequate and secure funding to achieve these objectives.

This white paper addresses the Delta ecosystem, drivers, stressors, constraints, and opportunities that will be considered in the Delta Plan to address the related policy objectives. The geographic focus of this white paper is the Delta and Suisun Marsh described as the legal Delta under State statutes.

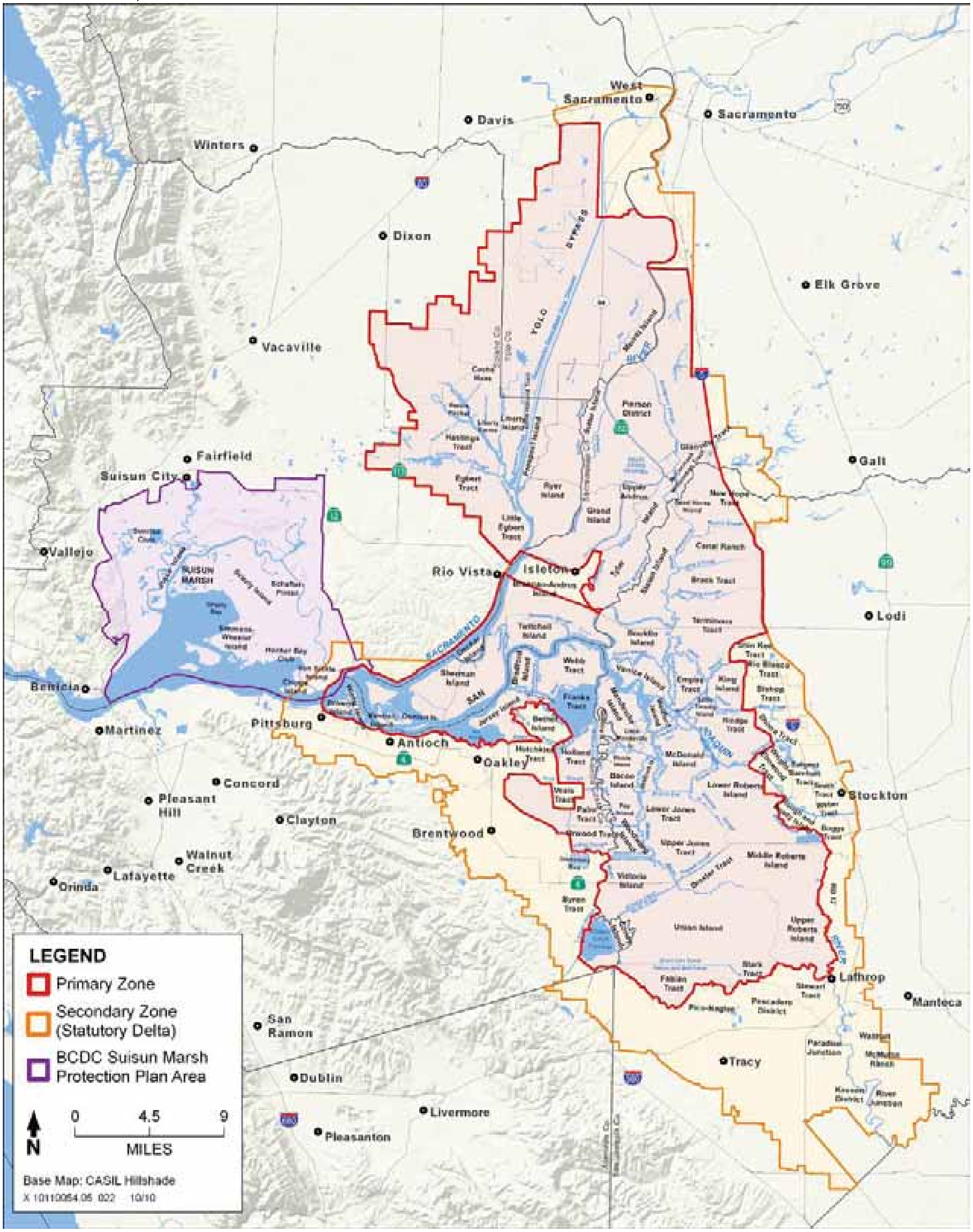
Section 2
Ecological Importance of the Delta

This section briefly describes the history, current conditions, and trends of the Delta and Suisun Marsh ecosystems, and is divided into four parts. The first, *Predevelopment Conditions: Historical Delta Natural Communities*, describes historical Delta and Suisun Marsh ecosystems and how they functioned prior to major modifications in land use and water use beginning in the 1850s. The second, *Modern Natural and Agricultural Communities*, briefly describes the major habitats and associated species occurring in the Delta and Suisun Marsh today. The third, *Decline of Upper Estuary Dependent Species*, provides an introduction to some important indicator species in the Delta and Suisun Marsh. The fourth and final part, *Dependence of Formerly Widespread Species upon the Delta and Suisun*, describes two important examples of species that have become more dependent on agricultural habitats in the Delta due to loss of their natural habitat there and elsewhere.

The Sacramento-San Joaquin Delta and Suisun Marsh comprise, along with the San Francisco Bay, the largest estuary on the Pacific Coast (Figure 2-1). The Delta is one of a few major inverse river deltas of the world, with the wide part of the delta “fan” located upstream, in the Central Valley (most major deltas tend to be widest at their downstream end). The Delta represents the connection and confluence of a vast watershed, connecting inland streams and rivers originating from the Cascade, Coast, and Sierra Nevada ranges with the San Francisco Bay and Pacific Ocean. Approximately 40 percent of California’s land area and 50 percent of its total stream flow converges at the Delta, and the Delta supplies fresh water to two-thirds of the State’s population (California Department of Water Resources [DWR], 1995; U.S. Geological Survey [USGS], 1999).

The ecosystem of the Delta was historically very rich, supporting abundant populations of wildlife and fish. A wide array of plant, wildlife, and fish species depends on a healthy Delta ecosystem. Due to major declines in ecosystem functions of the Delta over the past 150 years, many species and sensitive communities are currently imperiled.

Figure 2-1
Overview of the Delta Region
The legal Delta, which is an inverse river delta, lies to the East, while Suisun Marsh represents the intermediate portion of the estuary between the legal Delta and San Francisco Bay.
Source: AECOM, 2010



Predevelopment Conditions: Historical Delta Natural Communities

Prior to major water and land use changes, the Delta was predominantly characterized by vast tracts of intertidal wetlands and their associated connected waterways. Within this immense marsh plain, natural levees along the Sacramento and San Joaquin rivers supported riparian forest and scrub habitat, while floodplains, nontidal wetlands, inland dunes, grasslands, and seasonal wetlands created a mosaic of habitats at the perimeter of the marsh plain. This incredibly productive and complex ecosystem historically supported a great diversity and abundance of fish and wildlife, many of which moved freely between the mosaic of habitats present within the ecosystem (Bay Institute, 1998). Developing an understanding of how the Delta and Suisun Marsh ecosystems functioned before major development, when fish and wildlife populations were abundant and water quality was high, is fundamental to developing a Delta Plan that protects, restores, and enhances the Delta ecosystem in the future. Some of the historical habitats of the Delta and Suisun Marsh and their associated wildlife are described in greater detail below.

Intertidal Wetlands, Rivers, and Sloughs

The intertidal wetlands of the Delta, which include tidal marsh, tidal mudflats, and associated intricate networks of branching waterways, covered approximately 87 percent of the legal Delta in the mid-19th century (321,000 acres or 502 square miles) (Bay Institute, 1998; Atwater and Belnap, 1980). Such intertidal wetlands and open water were also predominant in Suisun Marsh, which was freshwater much of the year but often brackish during dry summer months (Moyle et al., 2010; Bay Institute, 1998). Intertidal wetlands of the Delta developed in flat sea-level terrain, primarily on peat soils that had accumulated from the decay of marsh vegetation over millennia. In the south-central Delta, peat soils were up to 40 feet thick.

Intertidal wetlands of the Delta and Suisun Marsh consisted of spatially complex mosaics of emergent marsh vegetation (often dominated by the common tule), other plant assemblages, pools and ponds, and tidal mudflats (Bay Institute, 1998). The vegetation composition of tidal marshes differed between the north and south Delta, with the north Delta being characterized by a matrix of tule marsh intersected by broad natural levees supporting riparian forest, while the south Delta was characterized by greater abundances of patchy willow scrub within great expanses of tule marsh (Atwater, 1980; Bay Institute, 1998).

Intertidal wetlands of the Delta were freshwater ecosystems; it is thought that brackish water only occasionally intruded beyond Suisun Marsh except during severe, multi-decadal droughts (Moyle et al., 2010). Intertidal marshes in Suisun Marsh became brackish during summer months and droughts when inland freshwater flows were lowest; thus, the intertidal marshes of Suisun Marsh had slightly different composition and associated wildlife compared to the more predominantly freshwater marshes of the Delta, but with a great degree of overlap.

These intertidal wetlands were extremely productive, and along with riparian forests are estimated to have produced 800 grams per square meter of organic material per year (Atwater et al., 1979) with an estimated total productivity of 915 million pounds of organic carbon sequestered per year by plant growth (Bay Institute, 1998 pp. 2-75). Intertidal wetlands of the Delta and Suisun Marsh were intricately dissected by small sloughs and channels; these intricate systems were described by an early explorer as “a terraqueous labyrinth of such intricacy that unskillful and inexperienced navigators have been lost for many days in it, and some, I have been told, have perished, never finding their way out” (Bryant, 1846 p. 343, *in* Bay Institute, 1998 pp. 2-58).

The deeper open waterways of the Delta (rivers and major sloughs) covered an additional estimated 25,000 acres (39 square miles) or 7 percent of the legal Delta, circa 1850 (Atwater and Belknap, 1980). Such subtidal waterways are characterized by open water even at the lowest of tides and are the major conduits of freshwater movement through the Delta (Bay Institute, 1998). In some places, mid-channel "islets" formed in the bends of larger waterways, which supported riparian vegetation, particularly in the south-central Delta (Bay Institute, 1998).

Fish and wildlife populations benefited greatly from the high productivity and complexity of the intertidal wetlands and sloughs of the Delta. A large community of detritus feeders, scavengers, and other benthic invertebrates was supported by the high levels of plant productivity and decay characteristic of Delta wetlands. These invertebrates in turn provided a strong foundation for the higher food chain, supporting abundant fish and waterbirds. Various terrestrial wildlife species foraged in historical intertidal wetlands and associated waterways of the Delta, including grizzly bear and tule elk along the periphery, tundra swan, sandhill crane, raccoon, beaver, river otter, and mink (Bay Institute, 1998).

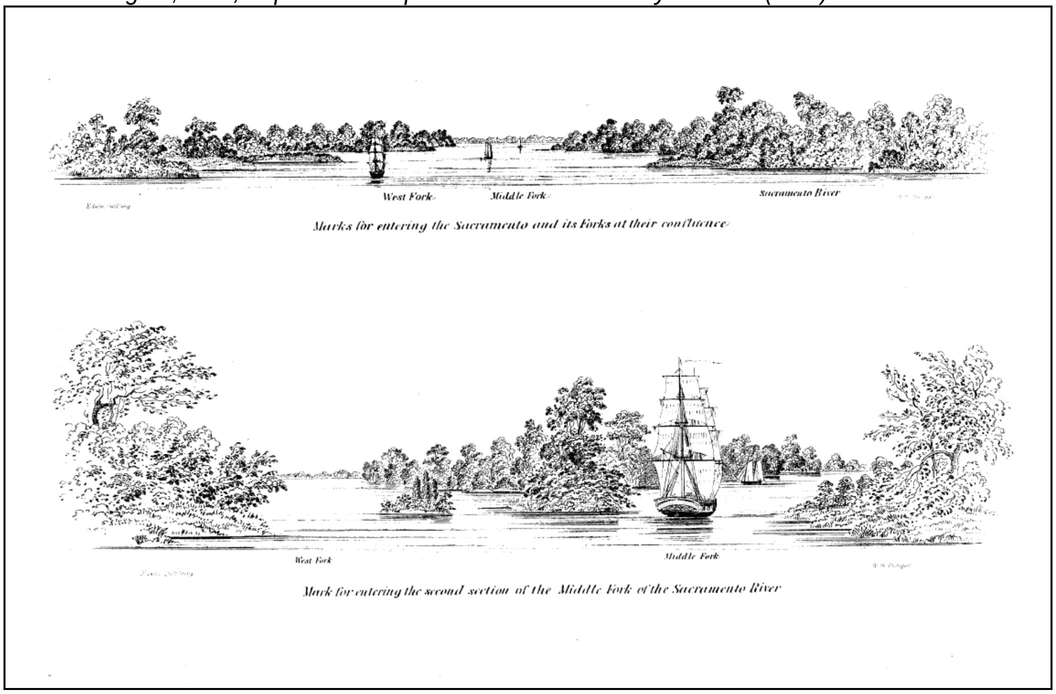
Many of the resident native fish of the historical Delta were large freshwater minnow species, including Sacramento splittail, Sacramento pike-minnow, hitch, and thicktail chub. Other resident fish included the delta smelt, longfin smelt, Sacramento sucker, and tule perch. The Delta also provided important habitat for historically abundant anadromous fishes including salmon, steelhead, and sturgeon, which dependon the Delta ecosystem during their migrations between their spawning habitat in upland rivers and their foraging habitat in the Pacific Ocean, and for rearing habitat during their juvenile life stage (Bay Institute, 1998). Many of the fishes that were previously very abundant in the Delta are endangered, threatened, or extinct today.

Riparian Forest and Scrub

Riparian forest and scrub was prevalent on natural levees throughout the Delta, but particularly expansive around the Sacramento River where sediment deposition and natural levee formation was greatest; natural levees around the Sacramento River were generally high and broad (e.g., 75 feet wide and up to 14 to 25 feet high) (McClure, 1925; Ringgold, 1852; CCPW, 1895: all *in* Bay Institute, 1998). These natural levees were important components of the Delta ecosystem, and natural levees and sand mounds comprised almost 25,000 acres or 7 percent of the Delta in the mid-19th century (Atwater and Belknap, 1980; Bay Institute, 1998). Natural levees were located at elevations above the influence of tides, and supported interconnected networks of streamside riparian forest and riparian scrub (Figure 2-2). Riparian forest also grew in mid-channel islets of rivers, particularly in the south-central Delta, as described above (Bay Institute, 1998). Eastside tributaries, including the Cosumnes, Mokelumne, and Calaveras rivers, also supported corridors of riparian forest.

Common riparian species included valley oak, western sycamore, Fremont cottonwood, willows, understory shrubs such as California rose and blackberry, and bunchgrasses. Riparian forests were important habitat for many species, providing forage, cover, and protection for Swainson's hawk, yellow-billed cuckoo, mule deer, beaver, bobcat, raccoon, riparian brush rabbit, and others (CALFED, 2000; Bay Institute, 1998). Riparian forests also enhanced adjacent aquatic habitats for fish by providing canopy cover and important nutrient inputs (leaf litter, insects), while reducing water temperature and stabilizing river channels (CALFED, 2000).

Figure 2-2
Historical Sketch of the Lower Sacramento River
This 1852 sketch of the Sacramento River near the confluence with Steamboat Slough shows extensive riparian forest along natural levees and mid-channel islands.
Source: Ringold, 1852; Reprinted with permission from The Bay Institute (1998).



Nontidal Wetlands

Nontidal wetlands were restricted to the perimeter of the Delta beyond the range of tidal influence, as well as in some locations in the north Delta around the Sacramento River where the formation of natural levees disconnected the tule wetlands from tidal waters and left them as nontidal marshes (Atwater, 1982 in Bay Institute, 1998, p. 2-57). Depressions within floodplains also supported nontidal wetlands, which were maintained by regular overbanking of water from the rivers during flood events. Nontidal wetlands were important habitat for most species associated with intertidal wetlands, and were likely preferred by marsh-nesting birds as well as the giant garter snake.

Grasslands, Floodplains, and Seasonal Wetlands

Grasslands and associated seasonal wetlands including vernal pools, alkali seasonal wetlands, and seasonally inundated floodplains surrounded the perimeter of the Delta. Seasonal wetlands such as vernal pools, alkali seasonal wetlands, and wet meadows were associated with soils having poor drainage, which held standing water after rains or after flooding from nearby waterways, forming small ponds in depressions that persisted through the spring. These pools, ponds, and playas were productive habitat for many unique aquatic invertebrate species, amphibians such as western spadefoot toad and California tiger salamander and locally endemic plants, many of which are endangered or threatened today. In general, these upland and seasonally ponded grasslands and seasonal wetlands were important components of the Delta ecosystem, supporting many plants and wildlife, including sandhill crane, ducks, geese, shorebirds, and mammals such as San Joaquin kit fox, bobcat, ground squirrel, kangaroo rat, tule elk, grizzly bear, and deer. Floodplains also provided important seasonal spawning and foraging habitat for fish such as splittail and forage for outmigrating juvenile salmonids (Sommer et al., 2001; Feyrer et al., 2006; Kimmerer et al., 2008).

Inland Dune Scrub

Sand mounds were formed by sediment deposition primarily in the west-central Delta, and many of these supported inland dune scrub, a unique and relatively rare community type even historically. This community supported many plant and insect species that were specifically adapted to that habitat and were locally endemic (geographically restricted) to those sites, such as Lange's metalmark butterfly.

Modern Natural and Agricultural Communities

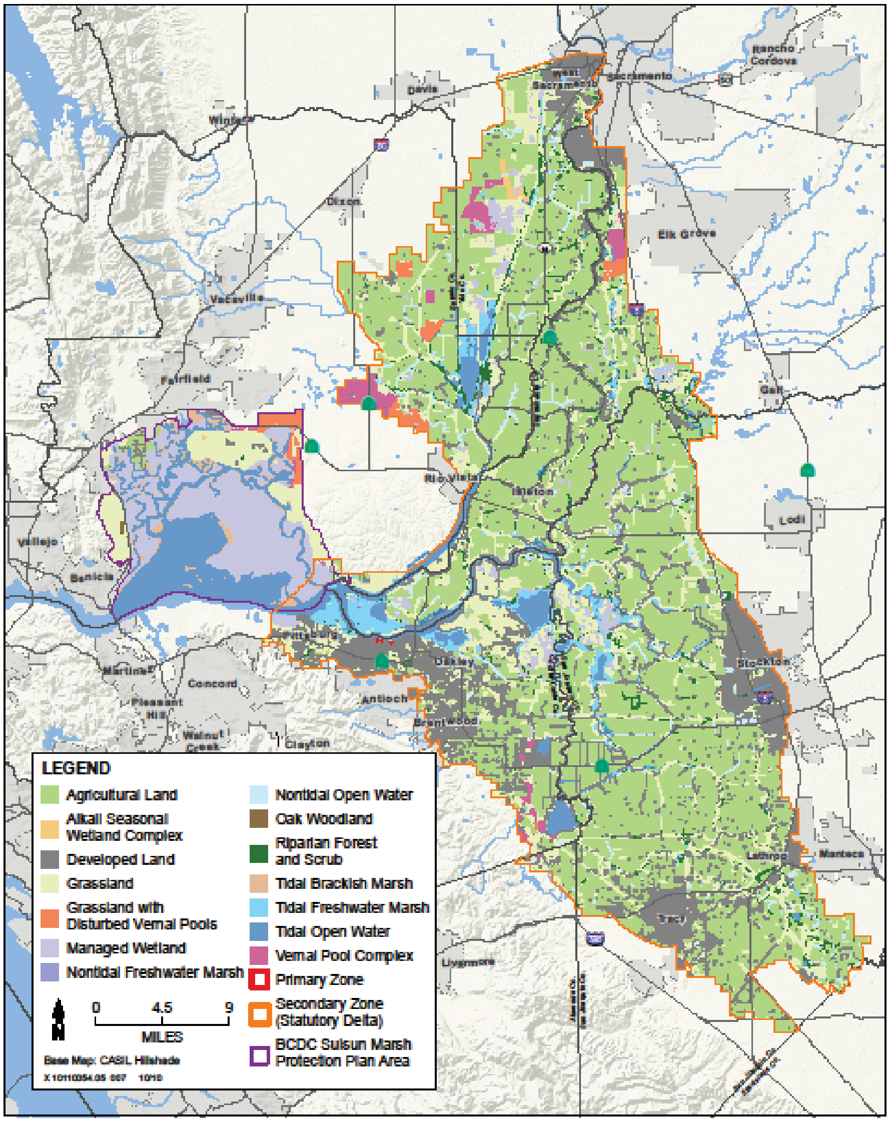
Today, the dominant land cover of the Delta is agricultural lands, while in Suisun Marsh the dominant land cover is managed wetland (Table 2-1, Figure 2-3). Remaining natural communities, such as tidal marsh, floodplain wetlands and riparian forests, are only a small fraction of their predevelopment acreage. In spite of these area differences, the variety of natural communities that was present in the mid-19th century is still present today for the most part, but the quality of habitat for native species of the natural communities has generally declined because of a number of human-induced effects, including habitat fragmentation, nonnative invasive species that negatively affect habitat quality for native species, reductions in water quality due to wastewater discharges, pesticide use and industrial waste, and water management.

Table 2.1
Land Cover Types in the Delta and Suisun Marsh

Land Cover Type	Delta (acres)	Percentage	Suisun Marsh (acres)	Percentage
Agricultural Lands	487,653	66.1	2,719	2.6
Developed	68,727	9.3	2,221	2.1
Tidal Open Water	61,750	8.4	24,490	23.5
Grassland	57,798	7.8	15,743	15.1
Managed Wetland	16,760	2.3	47,662	45.7
Riparian Forest and Scrub	16,264	2.2	152	0.1
Tidal Freshwater Marsh	8,947	1.2	0	0.0
Vernal Pool Complex	6,684	0.9	274	0.3
Nontidal Open Water	4,952	0.7	41	0.0
Alkali Seasonal Wetland Complex	3,591	0.5	146	0.1
Grasslands with Disturbed Vernal Pools	2,476	0.3	2,336	2.2
Nontidal Freshwater Marsh	1,134	0.2	0	0.0
Tidal Brackish Marsh	343	< 0.1	8,008	7.7
Other Natural Seasonal Wetlands	265	< 0.1	0	0.0
Inland Dune Scrub	19	< 0.1	0	0.0
Oak Woodland	0	0.0	492	0.5
Total	737,364	100.0	104,284	100.0

Source: DFG 2007, SAIC 2009, AECOM 2010

Figure 2-3
Land Cover Types of the Delta and Suisun Marsh
Source: SAIC 2010



Source: DFG 2007, SAIC 2009, AECOM 2010

As a result of these extensive historical modifications, the abundance and diversity of native wildlife and plants have been reduced over time in the Delta and Suisun Marsh. Because of habitat loss, large mammal species such as tule elk and grizzly bear have disappeared; small mammal species, such as riparian brush rabbit, have been reduced in number and now occur only in scattered locations. Some species that used the Delta ecosystem have gone extinct, such as the thicktail chub and the Sacramento tui chub (Moyle, 1973), while many others have been locally extirpated. However, the Delta and Suisun Marsh lie in a central portion of the Pacific Flyway and continue to provide vital migratory, wintering, and breeding habitat for shorebirds and migratory birds.

In addition to natural communities, agricultural lands provide habitat for some species that have adapted to use agricultural habitats in the place of the grasslands and tule marshes that previously existed there. For example, alfalfa fields provide foraging habitat for raptors, fields with grain crops provide foraging habitat for sandhill cranes and other birds, and orchards provide roosting habitat for bats.

Because of loss of habitat and reduction of habitat quality, numerous native species have become so rare that the State and federal governments have determined that these native species need protection under the State and federal Endangered Species Acts as threatened and endangered species. These protections constrain the current uses of land and water in the Delta and Suisun Marsh. This section describes the current conditions of natural communities and agricultural habitats and the native species they support, including threatened and endangered species.

Aquatic Communities (Bays, Rivers, Sloughs, Flooded Islands)

Aquatic communities in the Delta and Suisun include natural waterways (rivers and sloughs), constructed waterways (ship channels, conveyance channels, and connecting canals), natural embayments, and flooded islands. Within the geographic extent of Suisun Marsh and the Delta, these waterways are tidally and fluvially influenced. Humans have constructed numerous “connecting” waterways throughout the Delta for shipping and water supply conveyance. Connecting what were naturally disconnected waterways that produced significant heterogeneity in the aquatic environment has radically altered flow geometry and homogenized the aquatic environment, changing flow routes and residence time that affects fish, their food resources, and water quality, especially salinity variability and natural seaward salinity gradients. The current water surface area of the Delta is about 57,000 acres, excluding Liberty Island and Little Holland Tract which add another 6,000 acres. Suisun has about 26,000 acres of open water.

The aquatic community supports over 50 fish species, about one-half of which are native species (U.S. Fish and Wildlife Service [USFWS], unpublished data). This habitat is used by fish for foraging, spawning, egg incubation and larval development, juvenile nursery areas, and migratory corridors. Native fish that are found in tidal portions of the aquatic community include Delta smelt, Sacramento splittail, Chinook salmon, steelhead, and sturgeon. Native fish that are (or were) found in some nontidal areas (primarily ponds and lakes) include the Sacramento perch, hitch, and tule perch (Moyle, 2002). Tidal areas are also used by a variety of nonnative fish species such as inland silverside, sunfish, bass, and shad. Nontidal areas support many nonnative freshwater fish species, including sunfish, common carp, inland silverside, fathead minnow, and western mosquitofish.

Tidal aquatic communities provide reproductive, foraging, and resting habitat for many species of mammals and birds. Open water supports habitat for resting and foraging water birds such as loons, pelicans, gulls, cormorants, and diving ducks (CALFED, 2000). Nontidal areas of the aquatic community are used for resting and foraging by a variety of wildlife, including waterfowl, shore birds, semi-aquatic mammals (e.g., beaver, muskrat, and river otter), and birds and bats that prey on insects that gather over open water. Ponds and other small bodies of open water also serve as important brooding areas for ducks nesting in nearby upland habitats.

Aquatic communities in the Delta and Suisun Marsh support two types of vegetation: submerged aquatic vegetation (SAV) and floating aquatic vegetation (FAV). SAV are plants rooted to the bottom and that grow wholly within the water column. FAV are not necessarily rooted to the bottom and their photosynthetic float on the water surface, with plant matter partially above and partially below the water surface. The geographic extent of vegetation within the aquatic community varies over time in response to physical factors such as depth, turbidity, water flow, wind, salinity, substrate, and nutrient availability.

Submerged aquatic plants include native species such as water primrose, pondweed, and invasive species such as Brazilian waterweed and Eurasian watermilfoil. Pondweed grows in soft sediment in sheltered subtidal areas, primarily in the far western Delta and in Suisun Marsh where salinities are sufficiently high for this brackish water species. Common species of floating vegetation include duckweed, native floating water fern, and nonnative invasive water hyacinth.

Tidal Marsh

Tidal marsh developed in the San Francisco Estuary and Delta during the past few thousand years when the rate of sea level rise following the end of the last ice age slowed enough for wetland vegetation to establish. This period is known as the Holocene and the marshes that formed during this period are called *Holocene tidal marshes.* Sea level was roughly 300 feet below modern levels about 12,000-15,000 years ago, with the ocean shoreline located west of the Farallon Islands. As sea level rose and drowned the great river valley that is recognized today as the San Francisco Estuary and Delta, marshes formed along the more sheltered edges of the estuary. Over time, thick layers of peat accumulated as the marshes continued to build upwards. At the upland edges, marshes formed directly atop the flooded hillslopes and river floodplains, and that marsh-upland edge continued to migrate landward as sea level continued to rise. Sea level rise has never stopped; the oldest records in the United States are at the Golden Gate (since 1854) which has showed ongoing sea level rise of roughly 8 inches per century[1].

A vast majority of these Holocene tidal marshes have been lost to diking and filling. Of the 320,000 acres present in the Delta (Bay Institute, 1998) and 67,000 acres in Suisun Marsh (Monroe et al., 1999) around the time of California statehood, roughly 90 to 95 percent have been lost. Aside from a few in-channel islands, the Delta has no large tracts of Holocene tidal marsh remaining. The only Holocene tidal marshes left today in Suisun Marsh are Brown's Island at the confluence of the Delta and Suisun Marsh, Rush Ranch along Suisun Slough, Hill Slough, and Peytonia Slough, all of which total about 2,700 acres (San Francisco Estuary Institute [SFEI], 1998).

Hydraulic mining at placer mines in the Sierra Nevada mountains released nearly two billion cubic yards of sediment downstream (Gilbert, 1917). River flows transported the finer sediments downstream to Suisun Marsh and into San Francisco Bay where much of this sediment deposited and formed new tidal marsh along the banks of bays and sloughs, forming what are known as *Centennial tidal marshes.* Many of these marshes were reclaimed alongside the Holocene tidal marshes and some remain as tidal marsh today. These newly formed Centennial tidal marshes are often simpler geomorphically, especially lacking the complex tidal channel networks.

Tidal marshes occupy the intertidal and, in freshwater environments such as the Delta, shallow subtidal elevation ranges. Tide ranges in the Delta today are around 1 meter (3 to 4 feet) and about 2 meters (6-7 feet) in Suisun (DWR, 2004). Tidal marshes themselves consist of several distinct landform elements: vegetated marsh plains, channel slough networks that are very sinuous (having many turns) and dendritic (branching multiple times) with depths that can be subtidal or intertidal, higher elevation channel banks were the highest tides deposit their sediment loads, ponds on the marsh plain that may hold water temporarily and permanently, ponds along the marsh-upland edge that capture local runoff as well as extreme high tides, and mudflats along the banks of channels and at the water-side marsh edge except in low-energy freshwater environments where vegetation colonizes these areas.

Tidal marsh plant communities reflect the tidal inundation regimes (mainly elevation but also proximity to tidal channels and sloughs) and water salinity (Figure 2-4). In freshwater environments such as the Delta, freshwater tule marsh can grow below low tide where the plant species have high tolerance to submergence. Tules and cattails dominate the lower and mid-elevation tidal marshlands of the Delta (Figure 2-5). The higher-elevation tidal marshes of the Delta support a more diverse plant assemblage including rushes, sedges, and some salt-tolerant species such as salt grass. The brackish tidal marshes of Suisun are the most floristically diverse marshes in the Estuary, as they support a broad mixture of

[1] http://tidesandcurrents.noaa.gov/publications/150_years_of_tides.pdf

freshwater plant species growing in their most salt-tolerant conditions alongside salt-tolerant species (e.g., pickleweed, bulrush, salt grass) growing in a more freshwater setting. The salt stress of the brackish marshes prevents tules and cattails from growing as low in the tidal range as that found in the Delta. The marsh-upland transition tends to support very different vegetation in the Delta vs. Suisun Marsh, with the Delta supporting more riparian scrub and tree species as well as grasses and Suisun supporting mainly a variety of grasses though riparian scrub and trees are found near local tributaries.

Figure 2-4
Generalized Tidal Marsh Profile with Adjacent Uplands and Open Water
(Source: Moffatt & Nichol and Stuart Siegel, 2007).

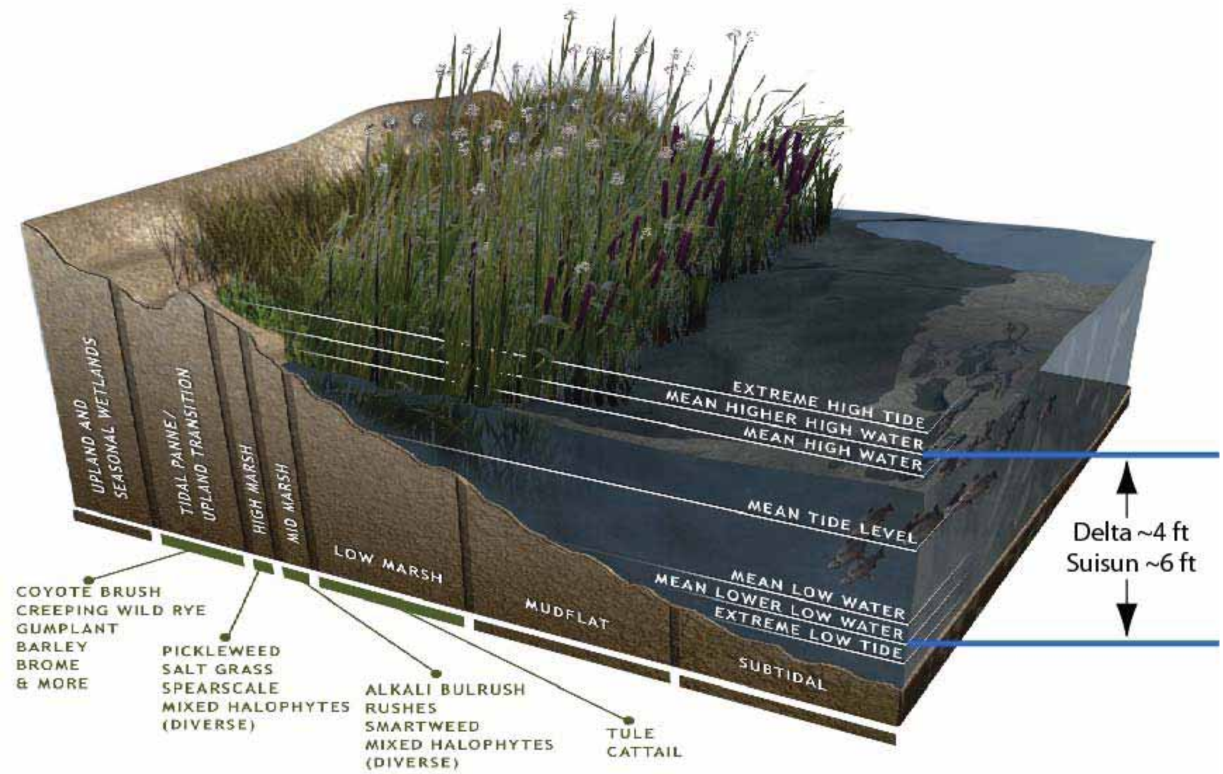


Figure 2-5
Tidal Marsh
The common tule is prominent component of tidal marsh at Lower Sherman Island
Source: AECOM, 2006

Key special status species supported by the tidal marshes of the Delta and Suisun Marsh differ somewhat. In the most saline regions of Suisun Marsh, the tidal marshes support salt marsh harvest mouse and California clapper rail both of which are at the eastern extent of their range due to less saline conditions. Suisun Marsh and the Delta support black rail. Giant garter snakes can use the freshwater tidal marshes of the Delta so long as they are close to upland overwintering habitat.

Two very rare plants found in Suisun Marsh's tidal marsh are the State-listed rare and federally listed endangered soft bird's beak and the federally listed endangered Suisun thistle. Rare plants in the tidal marsh of the Delta include the State-listed rare Mason's lilaeopsis, which occurs also on mudflats, along with a number of other special-status plants.

Brackish and fresh tidal marshes are biologically exceptionally productive, and at high tide, an assemblage of small or juvenile fish and invertebrates feeds on the large quantities of algae, detritus, and invertebrates originating from the marsh plane. Small and juvenile fish also may find shelter from predatory fish that occur in the open subtidal habitats. However, the importance of tidal marsh as nursery areas, which has been clearly established in other regions (e.g., east coast of the United States), has not been clearly demonstrated in the Delta or Suisun Marsh due to a combination of lack of marshes to study and lack of studies in those marshes (Brown, 2003b).

Many shallow subtidal areas throughout the Delta and Suisun Marsh currently support invasive submerged aquatic vegetation including Brazilian waterweed which provides habitat for nonnative fish such as striped bass and largemouth bass that are predators of native fish species such as delta smelt and salmonids (Grimaldo et al., 2004; Kimmerer et al., 2008; Nobriga, 2008).

Floodplain Wetlands and Riparian Forest and Scrub

Flood basins in the Sacramento and San Joaquin valleys overflow during the wet season and historically supported extensive nontidal seasonal wetlands and riparian forest and scrub. Today, these areas are generally mostly used for agriculture, especially rice, and only support scattered patches of native wetland habitat. The river discharges at which these "bypasses" flood are now mostly determined by the elevation of passive weirs. During the years that these basins flood they provide habitat for a host of native fish species, including white sturgeon, Chinook salmon, and Sacramento splittail (Sommer et al., 2001; Feyrer et al., 2006; and Kimmerer et al., 2008). In the northern Delta the Yolo Bypass is an important flood control facility that supports rice fields and other agricultural crops, numerous wetlands that are specifically managed for waterfowl, and provides rearing habitat for salmonids (Sommer et al., 2001) and habitat for other native fish. Substantial acreage of managed floodplain wetlands occurs in the Yolo Bypass especially the DFG Yolo Bypass Wildlife Area, at Stone Lakes National Wildlife Refuge, Cosumnes River Preserve, and at a number of other DFG-owned Wildlife Areas. The lower Cosumnes River floodplain just upstream of the Delta supports a mixture of riparian forest and scrub and wetlands, mostly established through past restoration efforts. These perennial habitats are managed for wildlife rather than agriculture and support a wide range of nesting bird species as well as fish spawning and rearing (Cosumnes River Preserve, 2010).

Channel Margin Riparian Forest and Scrub

Limited fragmented channel margin (levee bank) riparian habitats remain in the Delta. Remnant patches of tall riparian trees, such as Fremont cottonwood, western sycamore, and Goodding's black willow occur, but the reproduction of these species is greatly impaired by hydrologic modifications and active levee maintenance. The number of species of nesting birds and mammals found in the Delta that depend on riparian habitat has declined in the last 150 years (Bay Institute, 1998).

Riparian communities occur along rivers and stream of the Central Valley and foothills of the Sierra Nevada and Coastal Ranges (i.e., the Valley/Foothill Riparian community) on relatively coarse, sandy sediments, especially on "natural levees" deposited by overbank flow of major rivers. Riparian forest remnants may in some cases be so sparse that they are considered "riparian woodlands." These communities occur along the Sacramento, San Joaquin, Mokelumne, and Cosumnes rivers, and other waterways.

Riparian habitat in the Delta is generally limited to highly fragmented, narrow remnants, often only one tree wide, mostly along the banks of leveed waterways (Figure 2-6). A few forest remnants, such as at Delta Meadows and Prospect Slough, provide a glimpse of what riparian forest in the Delta might have looked like 160 years ago. Riparian communities in the Central Delta probably were never very extensive because this area is located on finer sediment and was dominated by tidal marsh. Some in-stream channels in this area (e.g., Disappointment Slough) now have a mix of riparian vegetation and tidal marsh.

Figure 2-6
Riparian Trees on Constructed Levees
Riparian habitat in the Delta is typically sparse. It can develop on constructed levees, providing nesting habitat for raptors, including Swainson's hawk, and instream woody material that is an important component of aquatic habitat for fish.
Source: AECOM, 2009

Riparian habitats often function as movement corridors for wildlife species. Tall riparian trees may provide nesting opportunities for raptors, including the State-listed threatened Swainson's hawk and Fully Protected white-tailed kite. The State-listed endangered western yellow-billed cuckoo nests in larger tracts of riparian forests and has recently been discovered in the Delta after a 50-year absence. Riparian scrub may also provide nesting opportunities for a number of song-bird species, including the State- and federally listed least Bell's vireo, which is expanding its range north and has recently been found nesting north of the Delta in the Yolo Bypass. In some cases, riparian trees may support heron, egret, and cormorant rookeries. Riparian scrub may support blue elderberries that are the host plant for the federally listed threatened valley elderberry longhorn beetle. Blue elderberries can also be found in monotypic stands along ditches, roadsides, or levees.

Riparian forest and scrub is an important component of the land-water interface between aquatic and terrestrial ecosystems and contributes to aquatic habitat quality for native fish species, providing shade, instream cover, and food to fishes.

Diked Wetlands

Construction of levees to reclaim the Delta and Suisun tidal marshes eliminated most of the natural tidal wetlands. The diked wetlands that remained or established within the leveed lands can be classified into Delta and Suisun Marsh diked wetlands.

Delta Diked Wetlands

In the Delta (unlike in Suisun Marsh), conversion to agriculture drove wetland reclamation. Following levee construction and active crop cultivation, diked lands in the Delta underwent significant subsidence, reaching levels in excess of 20 feet subsidence in the interior central Delta. Diked nontidal freshwater marsh formed in the lowest points of Delta islands where pumping was ineffective. Diked nontidal freshwater marsh also forms readily in the maze of agricultural drainage ditches throughout the Delta; these wetlands are often removed regularly as part of routine agricultural operations. Today, there are approximately 10,000 acres of diked wetlands in the Delta, scattered throughout the region and with Prospect Island being the largest single tract. Several islands in the central Delta support large areas of managed wetlands, including Mandeville Island, Medford Island, Holland Tract, and Bradford Island.

Shallow emergent diked wetlands in the Delta (water less than 3 feet deep) are dominated by thick, highly productive stands of tules and cattails. Many irrigation ditches, canals, and other waterways on Delta islands will develop marsh vegetation if vegetation is not periodically removed to maintain capacity. These wetlands could provide habitat to a number of rare species including the State- and federally listed threatened giant garter snake. Nontidal marshes are important foraging and breeding habitat for a variety of wildlife species, including some of those species historically associated with tidal marshes; dense emergent vegetation provides concealment from predators.

Diked Managed Wetlands of Suisun Marsh

Suisun Marsh has a different history than the Delta. Wetland reclamation in Suisun Marsh took place in part for agriculture and in part to establish managed wetlands to support private waterfowl hunting clubs. Agricultural activities had a comparatively short life in Suisun Marsh, in part due to higher soil salinities making crop production far more difficult. Suisun has generally undergone far less subsidence than the Delta, in part due to soils having less organic matter to decompose and in part to active land use management as mostly seasonal wetlands not as actively promoting soil decomposition compared to conventional agriculture.

Suisun Marsh supports more than 50,000 acres of diked wetlands managed mainly for waterfowl hunting. Most of these wetlands are managed as seasonal wetlands, flooded to various depths from fall through spring and dried during the summer to facilitate vegetation management specifically targeted at promoting plant species, some native and some introduced species, suitable to produce food for waterfowl. The DWR has constructed a variety of water management infrastructure in Suisun Marsh designed specifically to reduce surface water salinities, in order to mitigate salinity increases from the large-scale Delta water exports by the State Water Project (SWP) and the Central Valley Project (CVP). Duck club water management regimes are tied in part to operations of these DWR facilities to help leach soil salts and maintain the diked marshes in as low salinity conditions as possible.

Grasslands

Grassland communities have been invaded by many nonnative annual grasses over the past 150 years and are currently dominated by these nonnative grasses, such as wild oats, various bromes and barleys, Italian rye-grass, and many other nonnative plants. In some areas of the Delta, the grassland community is interspersed with vernal pools, alkali seasonal wetlands, and other seasonal wetlands (discussed below).

Rare plant species that can sometimes be found in the grassland community that contains patches of these other vegetation types include alkali milk-vetch, Heckard's peppergrass, and San Joaquin spearscale.

The grassland community is composed of a spectrum ranging from natural to intensively managed vegetation dominated by grasses. At the more natural end of the spectrum, grasslands are composed of introduced or native annual and perennial grasses and forbs (nongrass herbaceous species) (Hickson and Keeler-Wolf, 2007). Grasslands near the southwestern edge of the Delta (i.e., in eastern Contra Costa County) may provide habitat to the State-listed threatened and federally listed endangered San Joaquin kit fox, and dispersal habitat for the State- and federally listed threatened California red-legged frog.

Agricultural Habitats

Major crops and cover types in agricultural production include small grains (wheat and barley), field crops (corn, sorghum, and safflower), truck crops (tomatoes and sugar beets), forage crops (hay and alfalfa), pastures, orchards, and vineyards. The distribution of seasonal crops varies annually, depending on crop-rotation patterns and market forces. Several agricultural land-use types, including alfalfa, pasture, and rice provide especially valuable wildlife habitat, and are discussed below.

Alfalfa

Alfalfa is an irrigated, intensively mowed, leguminous crop that constitutes a dynamic habitat for some wildlife. Vegetation structure varies with the growing, harvesting, and fallowing cycles. Alfalfa is rotated periodically with other crops, such as vegetables and cereal grains. It is a very productive crop that does not require frequent tilling, so it can support large populations of small mammals (e.g., voles) and invertebrate species. As a result, it provides high-quality foraging habitat for various wildlife, including wading birds, shorebirds, sparrows, and hawks. Some of these species, such as shorebirds, use the fields when they are periodically flood irrigated. Alfalfa can be particularly important as foraging habitat to Swainson's hawk, white-tailed kite, and other raptor species, which capitalize on high prey densities and cycles of increased prey availability when the fields are being irrigated and mowed.

Irrigated Pasture

Irrigated pastures are managed grasslands that are not typically tilled or disturbed frequently. They are usually managed with a low structure of native herbaceous plants, cultivated species, or a mixture of both. Pastures provide breeding opportunities for ground-nesting birds and burrowing animals. The burrowing animals are prey for Swainson's hawk, other raptor species, and coyote.

Rice

Rice is a flood-irrigated crop of seed-producing annual grasses. It is maintained in a flooded state until near maturation. Rice is usually grown in areas that previously supported natural wetlands, and many wetland-associated wildlife species use rice fields, especially waterfowl and shorebirds. Waste grain also provides food for species such as ring-necked pheasant and sandhill crane. Other wildlife species that use rice fields include garter snake, bullfrog, and wading birds that forage on aquatic invertebrates and small vertebrates. Rice fields provide habitat for a range of wintering waterfowl species in the Yolo Bypass. In particular, the practice of flooding rice fields in winter to allow rice stubble to rot, instead of burning rice stubble in fall, provides a wide variety of ducks and geese opportunities to loaf or forage in rice fields in winter.

Other Cultivated Crops

Other cultivated crops include grain and seed crops, as well as row crops and silage. Grain and seed crops are annual grasses that are grown in dense stands and include corn, wheat, barley, and others. Because the dense growth makes it difficult to move through these fields, most of the wildlife values are derived during the early growing period, and especially following the harvest, when waste grain is accessible to waterfowl and other birds, such as the State-listed threatened and fully protected greater sandhill crane, and the lesser sandhill crane. In some areas of the Delta, grain fields currently support a substantial proportion of the sandhill crane population that winters in California.

Although generally of lesser value to wildlife than native habitats, row crop and silage fields often support abundant populations of small mammals, such as western harvest mouse and California vole. These species in turn attract predators.

Rare Natural Communities

The Delta and Suisun Marsh support some rare natural communities, including vernal pools, alkali seasonal wetlands, and inland dune scrub. These communities provide habitat to assemblages of rare native plant and wildlife species. Historically, seasonal wetlands, moist grasslands, vernal pools, and seasonal and perennial river floodplain wetlands were found along the upland edges of the Delta and/or Suisun Marsh. In many areas, these wetlands have been lost to development, conversion to agriculture, and altered hydrology.

Vernal Pools

Vernal pools occur in complexes of interconnected and isolated groups of vernal pool wetlands and seasonal swales in a matrix of grassland. Vernal pools are seasonal wetlands that form in shallow depressions underlain by hardpan or a dense clay subsurface layer. These depressions fill with rainwater and surface runoff; the subsurface layers restrict infiltration into the subsoil and the depressions remain inundated throughout the winter, and sometimes as late as early summer. Vernal pool vegetation in California is characterized by a high percentage of native species. Many plant species, and a number of animal species associated with vernal pools, are restricted to vernal pool habitat and are State- or federally listed as threatened or endangered. In the Delta these include the federally listed threatened vernal pool fairy shrimp and federally listed endangered vernal pool tadpole shrimp.

Vernal pool complexes are found in a several locations along the margins of the Delta and Suisun Marsh. In the Delta, vernal pool complexes occur in the vicinity of Stone Lakes National Wildlife Refuge, Yolo Bypass, southeastern Solano County, and Clifton Court Forebay. Throughout these areas there are also grasslands with disturbed vernal pools, which provide habitat to the same species, including listed species. Several of these areas at the edge of the Delta are subject to urban development pressure.

Alkali Seasonal Wetlands

Alkali seasonal wetlands occur on alkaline soils with ponded or saturated soil conditions for prolonged periods during the growing season. The vegetation of alkaline seasonal wetlands is composed of salt-tolerant plant species adapted to wetland conditions and high salinity levels. This natural community “complex” includes both seasonally ponded and saturated wetlands and the surrounding matrix of grassland (Figure 2-7). It is currently typically found either at the historical locations of lakes or ponds in the Yolo Basin in and around the DFG Tule Ranch Preserve (Witham, 2003) where salts accumulated through evaporation, or in upland situations such as basin rims and seasonal drainages that receive salts in runoff from distant upslope salt-bearing rock, such as areas near Suisun Marsh and the Clifton Court Forebay (see Figure 2-3).

Figure 2-7
Alkali Seasonal Wetlands
Alkali seasonal wetlands in the southern Delta provide habitat for vernal pool fairy shrimp and other special-status species.
Source: AECOM, 2009

Alkaline seasonal wetlands can support a variety of species, and they often provide suitable habitat for a number of rare plant species. Dominant grasses in alkaline seasonal wetlands and surrounding grassland include saltgrass and wild barley. The Delta includes small stands of alkali sink scrub (also known as valley sink scrub), which are characterized by iodine bush. Although alkali seasonal wetlands support unique species they also have species in common with vernal pools. For example, vernal pool fairy shrimp occur in alkali seasonal wetlands near Clifton Court Forebay.

Inland Dune Scrub

Inland dune scrub is composed of vegetated, stabilized sand dunes associated with river and estuarine systems. In the Delta, the remaining patches of inland dune scrub community include remnants of low-lying ancient stabilized dunes related to the Antioch Dunes formation near the town of Antioch. The historical vegetation of these largely stabilized ancient interior dunes included perennial grassland, oak woodland, and local "blowout" areas (naturally disturbed, unstable, wind-eroded and depositional sites, or river-cut sand cliffs, within stabilized dunes) that supported the distinctive dune species that survive at the Antioch Dunes National Wildlife Refuge.

The remaining dune remnants in the Delta are highly fragmented and in many cases are dominated by nonnative weedy herbaceous vegetation. Stabilized sand dunes are found on Brannan Island, south of Dutch Slough, and in other small areas throughout the Delta. The Antioch Dunes support an assemblage of rare invertebrates that are unique to the area. These include the federally listed endangered Lange's metalmark butterfly, which is restricted to the Antioch Dunes. Two State- and federally listed plant species also occur at the Antioch Dunes, the Antioch Dunes evening primrose and Contra Costa wallflower.

Decline of Upper Estuary Dependent Species

One indicator of the poor ecological condition of the Delta and Suisun Marsh is the total number and diversity of species that are listed as rare, threatened, or endangered that depend in part or in whole on the Delta. Two fish species that utilized the Delta have become extinct: the thicktail chub and the Sacramento tui chub (Moyle, 1973). The abundance of some other species including the delta smelt has declined precipitously. Overall, approximately 100 wildlife species, 140 plant species, and 13 taxonomic units of fish in the Delta and Suisun Mash are considered special-status species, and are afforded some form of legal or regulatory protection (CNDDB, 2010; USFWS, 2010; CNPS, 2010).

The following provides an overview of some high-profile special-status species that occur in the Delta. Delta smelt, anadromous salmonids, and giant garter snake are largely dependent on the Delta ecosystem for their survival: Other special status species that were formerly abundant in the Delta and elsewhere but are now dependent on the Delta and Suisun Marsh for their continued survival due to habitat loss include greater sandhill crane and Swainson's hawk. The following descriptions are intended to provide a general understanding of these species' life histories and how changes in the Delta and current ecosystem stressors have contributed to their decline.

Delta Smelt

Delta smelt are endemic to the Bay-Delta estuary. The geographic distribution of delta smelt is primarily downstream of Isleton on the Sacramento River, downstream of Mossdale on the San Joaquin River, and Suisun Bay and Suisun Marsh. Delta smelt have also been collected in the Petaluma and Napa rivers. Delta smelt adults occur primarily in the tidally influenced low salinity region of Suisun Bay and the freshwater regions of the Delta and the Sacramento and San Joaquin Rivers (Moyle, 2002). Recent evidence suggests that a fairly large proportion of the delta smelt population inhabits the Cache Slough region during the summer (Sommer et al., 2009).

Delta smelt are semi-anadromous, spawning in the freshwater reaches of the San Francisco estuary, primarily in the Delta. Adult delta smelt spawn during the late winter and spring months, with most spawning occurring during April through mid-May (Moyle, 2002). After hatching, larvae disperse into low salinity habitats, generally moving into Suisun Bay, Montezuma Slough, and the lower Sacramento River below Rio Vista as they mature (Grimaldo et al., 1998). In general delta smelt prefer to rear in or just above the region of the estuary where fresh water and brackish water mix as a result of tidal and river currents; this region is typically in Suisun Bay (Bennett, 2005). Delta smelt are zooplanktivorous throughout their lives, feeding mainly on tiny organisms such as copepods, cladocerans, and amphipods with which they co-occur (Moyle et al., 1992; Nobriga, 2002).

Delta smelt were once abundant in the Delta, but indices of smelt abundance suggest that the delta smelt population declined abruptly in the early 1980s, but rebounded somewhat in the mid-1990s (Sweetnam, 1999). However, delta smelt numbers have trended precipitously downward since about 1999, as delta smelt and other pelagic fish species in the Delta have suffered what is known as the Pelagic Organism Decline (Sommer, 2007).

Delta smelt were listed as a threatened species under both the federal Endangered Species Act (ESA) and the California ESA in 1993. In 2009, the California Fish and Game Commission elevated the status of delta smelt to endangered under the California ESA in response to an emergency petition. Critical habitat for Delta smelt was designated by USFWS in 1995 (59 FR 65256). The designated critical habitat extends throughout Suisun Bay (including Grizzly and Honker bays), the length of Goodyear, Suisun, Cutoff, first Mallard and Montezuma sloughs, and the contiguous waters of the legal Delta.

Because of their short life span, low fecundity, current low abundance and limited geographic range, changes in the Delta have influenced the distribution and abundance of delta smelt (Moyle, 2002) in complex and synergistic ways. These changes have created a number of individual stressors that affect delta smelt at different times based on environmental conditions. Although typically treated as alternative mechanisms for the decline of Delta smelt, the effects of these stressors are not mutually exclusive. In reality, complex pathways of biological, environmental, and human processes likely determine annual abundance (Bennett and Moyle, 1996).

Delta smelt have been affected by loss of habitat and reductions in the quality of their habitat, largely as a result of changes in Delta inflows that affect salinity and human activities such as wetland and floodplain reclamation. There is evidence that the availability and suitability of delta smelt rearing habitat varies with location of the low salinity zone, measured as X2[2] (Moyle et al., 1992), although there is no strong evidence that X2 predicts delta smelt abundance (Armor et al., 2006). Overall, delta smelt recruitment is poor during drought and flood years, and highly variable during intermediate flow years when low salinity habitat is located in Suisun Bay. Adult abundance is always low when X2 is located in the lower Sacramento and San Joaquin rivers. The amount of spawning habitat may have been reduced as a result of reclamation, channelization, and riprapping of historical intertidal and shallow subtidal wetlands.

Large numbers of delta smelt are also lost to entrainment in the CVP and SWP water export facilities, various smaller facilities, and agricultural diversions in the Delta (Herren and Kawasaki, 2001). In addition, the CVP and SWP water export facilities and other diversions export phytoplankton, zooplankton, nutrients, and organic material that would otherwise support the base of the food web in the Delta, thus reducing food availability for delta smelt (Jassby and Cloern, 2000; Resources Agency, 2007). The risk of entrainment to delta smelt varies seasonally and among years. The greatest entrainment risk has been hypothesized to occur during winter when pre-spawning adults migrate into the Delta in preparation for spawning (Moyle, 2002; USBR, 2004).

The introduction of nonnative species has also adversely affected delta smelt. Introduced in the mid-1980s, the overbite clam has reduced phytoplankton and zooplankton abundance throughout the region (Kimmerer and Orsi, 1996) and altered the species composition of the zooplankton. The Asian clam has also contributed to reduced phytoplankton abundance in the Delta (Jassby et al., 2002; Thompson, 2007). Changes in the zooplankton species composition have affected the quality of food resources available to delta smelt because some of the nonnative zooplankton species are less suitable as a food resource than the native species (Resources Agency, 2007). Several potential nonnative fish predators of delta smelt have been introduced into the Delta, including largemouth bass, threadfin shad and inland silversides (Bennett, 2005). Inland silversides, in particular, could have had a dramatic impact by preying on eggs and larvae and then competing with juvenile delta smelt.

Brazilian waterweed and water hyacinth (both introduced plants) grow in dense aggregations and can indirectly affect delta smelt by reducing dissolved oxygen levels, suspended sediment concentrations and turbidity within the water column. Reduced turbidity as a result of these plants and filter feeding by the introduced clams may reduce foraging efficiency and increase the vulnerability of delta smelt to predation. Because of the structure and shade they provide, these aquatic plants also create excellent habitat for bass and sunfish, nonnative predators of delta smelt, (Nobriga et al., 2005).

[2] the location of the 2 parts per thousand salinity line, as measured in kilometers from the Golden Gate bridge

Numerous toxic chemicals, including agricultural pesticides, herbicides, heavy metals, and other agricultural and urban product, enter delta smelt habitat from a variety of sources (Thompson et al., 2000). Chemicals, such as pesticides, herbicides, endocrine disrupting compounds, and metals, may have lethal and sublethal effects on delta smelt that make them more vulnerable to other sources of mortality (Werner, 2007). Ammonia discharged from municipal wastewater treatment plants may also contribute to localized toxicity in delta smelt.

Anadromous Salmonids

The term anadromous salmonids refers to a group of fishes, including salmon and trout, that spend portion of their life at sea, but return to spawn in fresh water. In the Central Valley, Chinook salmon and steelhead, the primary anadromous salmonids, share a common life history that typically includes passage through the Delta twice during their lifetime: once as juveniles emigrating to the ocean from the Sacramento and San Joaquin rivers and their tributaries where they were born, and again as adults on their return migration to their natal streams to spawn. Salmon die after spawning, but adult steelhead may return to the ocean after spawning and make the journey more than once.

Young salmon and steelhead typically migrate toward the Delta enroute to the Pacific Ocean during winter and early spring, and use the Delta, Suisun Marsh, and the Yolo Bypass for rearing to varying degrees, depending on their life stage (fry vs. juvenile) and size, river flows, and time of year. The timing of upstream migration and spawning varies among species and within species, with various runs of Chinook salmon identified by their spawning migration period (i.e., spring-run, fall-run, late fall-run, and winter-run). Adult salmon and steelhead migrating into the Sacramento River and its tributaries primarily use the western and northern portions of the Delta, whereas adults entering the San Joaquin River system to spawn use the western, central, and southern Delta as a migration pathway.

In general, salmon and steelhead abundance has declined from historical levels and several runs have been reduced to low numbers or extirpated from some streams within their historical distributions (Yoshiyama et al., 1998; Good et al., 2005). Declining population numbers and continuing threats to salmonid populations have resulted in the listing of several Chinook salmon and steelhead populations under the Federal and State ESA. Several listed Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of salmonid species use the Delta during one or more of their life history stages. Critical habitat for these species generally includes their natal streams as well as the migration corridors and rearing areas in the Delta and Suisun Marsh.

Access to most of the historical upstream spawning habitat for Chinook salmon and steelhead has been eliminated or degraded by manmade structures (e.g., dams and weirs) associated with water storage, conveyance, flood control, and diversions and exports for municipal, industrial, agricultural, and hydropower purposes (Yoshiyama et al., 1998; McEwan, 2001; USBR, 2004; Lindley et al., 2006; NMFS, 2007). Upstream diversions and dams have decreased downstream flows and altered the seasonal hydrologic patterns. Reduced flows from dams and upstream water diversions result in spawning delays, increased straying, and increased mortality of outmigrating juveniles (Yoshiyama et al., 1998; DWR, 2005).

Channel margins throughout the Delta have been leveed, channelized, and fortified with riprap for flood protection and island reclamation, reducing and degrading the quality of habitat available for juvenile rearing. Modification of natural flow regimes due to upstream reservoir operations has resulted in a reduction in the extent and duration of seasonal floodplain inundation and other flow-dependent habitat used by migrating juvenile Chinook salmon (70 FR 52488; Sommer et al., 2001; DWR, 2005). Reduced flows have also resulted in increased water temperatures, increased residence times, and reductions in dissolved oxygen levels in localized areas of the Delta (e.g., Stockton Deep Water Ship Channel) that adversely affect the quality of rearing habitat for juvenile salmonids.

Predation on juvenile salmon by nonnative fish has been identified as an important threat to salmon and steelhead in areas with high densities of nonnative fish (e.g., small and large mouth bass, striped bass, and catfish) that prey on outmigrating juveniles (Lindley and Mohr, 2003). The invasion of nonnative aquatic vegetation, such as Brazilian waterweed and water hyacinth, has provided suitable habitat for nonnative fish that prey on juvenile salmon and steelhead (Nobriga et al., 2005; Brown and Michniuk, 2007). Channelized waterways (e.g., riprap-lined levees) provide virtually no cover protection from predators and low spatial diversity. The general lack of habitat diversity elsewhere in the Delta reduces refuge cover and protection of juvenile salmonids from predators (Raleigh et al., 1984; Missildine et al., 2001; 70 FR 52488).

Juvenile salmon and steelhead are also subject to entrainment at the SWP and CVP export facilities, various smaller facilities, and agricultural diversions in the Delta. There are multiple factors that can influence the vulnerability of juvenile salmon and steelhead to entrainment, including the geographic distribution of steelhead within the Delta and hydrodynamic factors, including reverse flows in Old and Middle Rivers. Salmon and steelhead respond behaviorally to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile migration through the Delta. Changes in these hydraulic cues as a result of SWP and/or CVP export operations during the migration period may contribute to delays in migration, attraction to false migration pathways, or increased movement of migrating salmon and steelhead toward the export facilities, which increases the risk that these fish will be entrained into the fish salvage facilities. Many juvenile salmon and steelhead migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels.

As a result of the extensive agricultural development within the Central Valley, exposure to pesticides and herbicides has been identified as a significant concern for salmon and other fish species (Bennett et al., 2001). Agricultural return flows are widely distributed throughout the Sacramento River and the Delta, although dilution flows from the rivers may reduce chemical concentrations to sublethal levels. Other contaminants of concern for salmon and steelhead include, but are not limited to, mercury, copper, oil and grease, ammonia, and localized areas of depressed dissolved oxygen (e.g., Stockton Deep Water Ship Channel). In addition, sublethal concentrations of toxics may interact with other stressors on salmonids, increasing their vulnerability to mortality as a result of exposure to seasonally elevated water temperatures, predation, or disease (Werner, 2007).

Coastal marine waters offshore of San Francisco Bay support a mixed stock fishery comprised of both wild and hatchery produced salmon. Harvest as a result of the commercial, recreational, and tribal fisheries may be detrimental to wild salmon and steelhead populations in this mixed stock fishery. Chinook salmon and steelhead are also subject to illegal harvest (poaching) in inland waters. Adult spring-run Chinook salmon are particularly vulnerable because they hold in pool habitat within streams where they are easily accessible during the summer months. The level and effect of illegal harvest on salmon and steelhead abundance and reproduction is unknown. Hatchery produced salmon and steelhead in the Central Valley also present multiple threats to wild salmonid populations, including competition for food and habitat, direct predation on wild fish, and interbreeding with wild fish that can reduce their genetic fitness (DFG, 1995; USFWS, 2001; Sommer et al., 2001b; USBR, 2004; Goodman, 2005)

Giant Garter Snake

The giant garter snake is listed as threatened by the State and federal governments. They occur in wetlands (primarily tidal and nontidal marshes and associated waterways) during their active season, and currently, the giant garter snake inhabits agricultural wetlands (e.g., rice fields) and other waterways (USFWS, 1999). They require higher elevation uplands for cover and refuge from floodwaters during their dormant season from October until April. Giant garter snakes feed primarily on small fish, tadpoles, and frogs, and are vulnerable to predation from both native species (e.g., raccoons, egrets, herons) and nonnative species (e.g., bullfrogs, feral cats).

The giant garter snake was historically distributed throughout the Sacramento and San Joaquin valleys, but no recent occurrences have been found in the northern San Joaquin Valley (Hansen and Brode, 1980). Before the Gold Rush, the giant garter snake probably only occurred along the edges of the Delta, primarily in non-tidal wetlands. Levee construction and conversion of tidal marsh to agricultural lands may have created opportunities for the giant garter snake to colonize nontidal wetlands and waterways in the interior Delta. However, giant garter snakes are only rarely found in the interior Delta, and occurrences in the western Delta may be result of snakes being carried there by flood flows. Recent records within the Delta are haphazard, and repeated surveys at focused locations within the Delta have failed to identify any extant population clusters in the region (Hansen, 1986; Patterson and Hansen, 2002; Patterson, 2005); however, the entire Delta has not been systematically surveyed. Recent or historical records of giant garter snake have been documented in the Delta north of State Route 4, especially in the White Slough Wildlife Area west of Interstate 5 at State Route 12. Recent findings have also demonstrated that giant garter snake is extant on Empire Tract (Swaim, pers. comm.), in the Yolo Basin (Hansen, 2007; CNDDB, 2010), and potentially in other areas within or near the Delta. There is concern that isolated populations may be subject to greater risk of extirpation (USFWS, 2006).

Habitat loss and fragmentation, flood control activities, changes in agricultural and land management practices (e.g., conversion of rice lands to orchards or cotton), predation from introduced species, parasites, water pollution, and continuing threats are the main causes for the decline of this species (USFWS, 1999). Human disturbance contributes to habitat degradation because giant garter snakes are diurnal predators that are disturbed by human activities.

Dependence of Formerly Widespread Species upon the Delta and Suisun

Although urban and agricultural development have led to loss of natural habitat for some special-status species occurring in the Delta, other special-status species have become dependent on agricultural habitats as their natural habitat has declined. Examples are the Swainson's hawk and greater sandhill crane. The Swainson's hawk used to spend its summers foraging in the grasslands of the Central Valley, but now depends on agricultural fields. The California population of the greater sandhill crane used to spend its winters foraging in freshwater wetlands, but now mainly spends the winter foraging in agricultural fields. Both species are briefly discussed in this section.

Swainson's Hawk

Swainson's hawk, a State-listed threatened species, is essentially a plains or open-country hunter, and requires large areas of open landscape for foraging. Historically, the species used the grasslands of the Central Valley and other inland valleys. With substantial conversion of these grasslands to farming operations, Swainson's hawks have shifted their nesting and foraging into those agricultural lands that provide low, open vegetation for hunting and high populations of rodents for prey (e.g., alfalfa fields and irrigated pasture). They nest in trees most often in riparian woodlands and farm shelterbelts (England et al., 1997), as well as in urban or suburban areas with large trees adjacent to suitable foraging habitat (James, 1992; England et al., 1995). Suitable nest trees are usually deciduous and tall (England et al., 1997). Fields lacking adequate prey populations, such as tidal marshes, flooded rice fields, or those that are inaccessible to foraging birds, such as vineyards and orchards, are rarely used (Estep, 1989; Babcock, 1995; Swolgaard, 2003). Meadow vole is the principal prey item in the Central Valley (Estep, 1989).

Historically, when much of the Delta was tidal marsh, the Delta probably provided only limited habitat for the Swainson's hawk. However, after conversion of marshes to agricultural fields, more foraging opportunities were created for Swainson's hawks in the Delta. Tall riparian trees provided nesting opportunities. As riparian habitat has declined over time, nesting habitat may have become more limited in the Delta, although in some cases ornamental trees may provide nesting opportunities.

Threats to Swainson's hawk include loss and fragmentation of foraging habitat, loss of nesting habitat, disturbance of nests, and pesticide poisoning in the Central and South American wintering habitat (DFG, 2005). Conversion from compatible to incompatible crop patterns reduces available foraging habitat and influences the distribution of nesting Swainson's hawks.

Greater Sandhill Crane

The greater sandhill crane is State-listed as threatened and fully protected. A "fully protected" listing means that no "take" of the species is allowed and incidental take permits cannot be issued by DFG. The population of greater sandhill crane that winters in the Central Valley breeds in northeastern California, central and eastern Oregon, southwestern Washington, and southern British Columbia (Littlefield and Ivey, 2000). Greater sandhill cranes are primarily birds of open freshwater wetlands. In California, nesting typically occurs in open grazed meadows. Wintering habitat consists of three primary elements: foraging habitat, loafing habitat, and roosting habitat. In the Delta, harvested corn fields are the most commonly used foraging habitat along with winter wheat, alfalfa, pasture, and fallow fields (Pogson and Lindstedt, 1988). Loafing generally occurs at midday when birds loosely congregate along agricultural field borders, levees, rice checks, or ditches, or in alfalfa fields or pastures. Roost sites, which provide protection from predators during the night, are typically within 2–3 miles of foraging and loafing areas, and thus available roosting sites are an essential component of winter habitat. Roosting habitat typically consists of shallowly flooded open fields of variable size or wetlands interspersed with uplands.

Historically, when much of the Delta was tidal marsh, greater sandhill cranes probably were mostly confined to the edges of the Delta, and river floodplain wetlands. After conversion of tidal marshes to agricultural fields, cranes have shifted their foraging habitat to agricultural fields (e.g., corn), while often using managed wetlands as roosting habitat. Currently, the Delta provides approximately two-thirds of the wintering habitat of the California population of greater sandhill crane (Pogson and Lindstedt, 1988; Littlefield and Ivey, 2000), which is probably a larger fraction than it was historically. In recent years, conversion of suitable crops for foraging (e.g., corn) to unsuitable crops (e.g., vineyards and orchards) has reduced foraging habitat for the greater sandhill crane in the Delta.

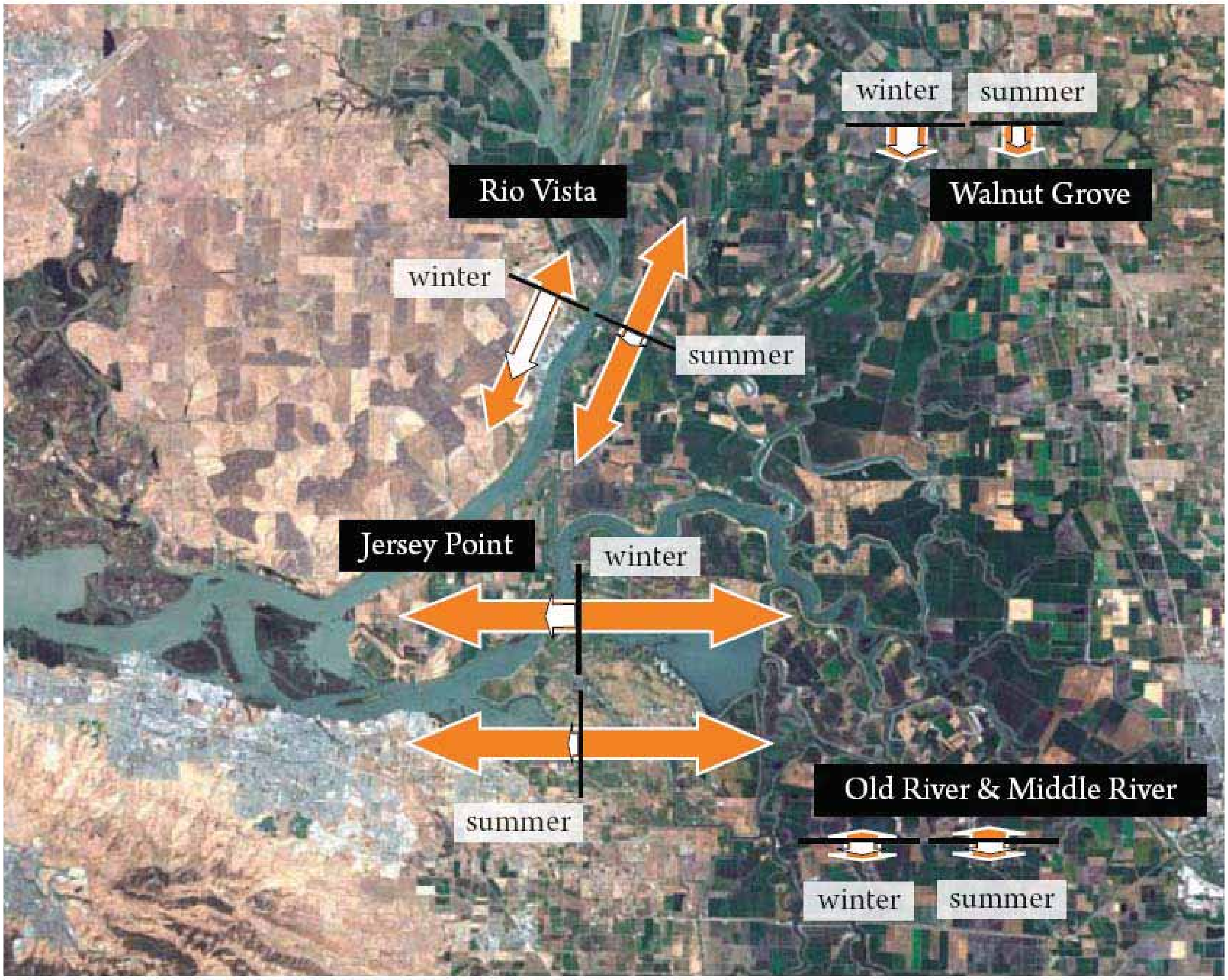
Threats to the wintering grounds of the greater sandhill crane include changes in water availability; flooding of fields for waterfowl, which reduces foraging habitat for cranes; conversion of cereal cropland to vineyards or other incompatible crop types; human disturbances; collision with power lines and other structures; disease; and urban encroachment (Littlefield and Ivey, 2000).

Section 3 Estuarine Mixing: Tides, River Flows and Resulting Salinity Variability Are Key to Estuarine Ecology

Estuaries are generally recognized as places where fresh water from the land mixes with salt water from the coastal ocean within a semi-confined area. The San Francisco Estuary, which includes the Delta and Suisun Marsh, is characterized more specifically as an "inlet of the sea reaching into a river valley as far as the upper limit of tidal rise" (Fairbridge, 1980). The importance here is the emphasis upon the strong tidal nature of estuaries even in areas like the Delta that are predominantly fresh water. Variability in the physical and chemical attributes of the water across time and space driven by the mixing of salt water and fresh water and the complexity and diversity of natural habitats are the hallmarks of estuaries (Moyle et al., 2010). This variability and complexity reflects seaward gradients in salinity and other water quality parameters, the diversity and geographic distribution of natural habitats, and the presence of floodplain habitats along the rivers entering the estuary. As a result of these and other factors, estuaries are tremendously productive and biologically diverse. The San Francisco Bay-Delta estuary now lacks many of these critical attributes and modern management activities reduce the exact variability essential to high estuarine productivity in order to meet salinity needs for in-Delta and exported uses.

In natural estuaries, estuarine variability and complexity arises from the interaction of two dynamic systems, rivers and coastal oceans, meeting in confined geologic space. Ocean tidal energy provides the regular cycle of flows and water elevations that interacts with the geometry of the estuary (the actual landscape features of channels, marshes, etc.) and the roughness of the estuary (friction that slows water flow) to govern local tide ranges, flow patterns, and mixing with the inflowing fresh water (Figure 3-1). This complex tidal mixing of fresh and salt water is the key process promoting estuarine variability and it establishes the key gradients in ecologically important water quality parameters (e.g., salinity, turbidity, temperature). Without this complexity in mixing processes, the heavier salt water would simply remain below the lighter fresh water (Lucas et al., 2006, as cited in Moyle et al., 2010).

Figure 3-1
Tidal and Net Flows in Different Regions of the Delta in Winter and Summer Under Modern Flow Management Conditions
Source: Kimmerer et al., 2008



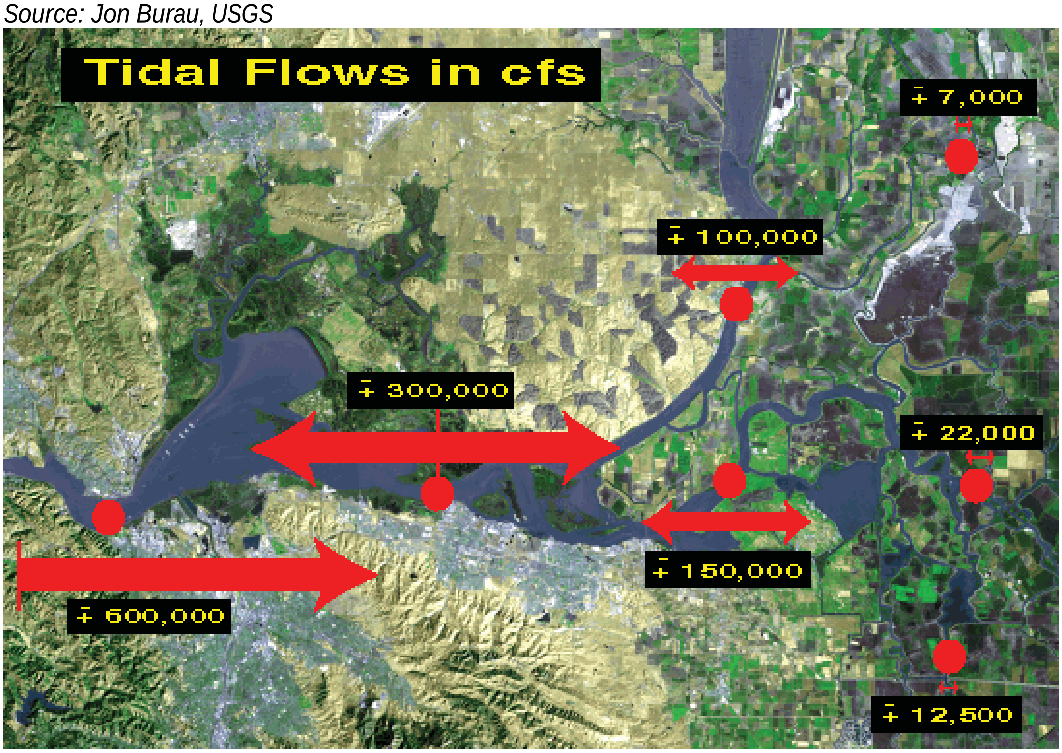
Orange arrows show tidal flow, white arrows show net flow (combination of tidal and riverine). Note greater winter vs. summer net flows at Rio Vista and Jersey Point. Note Old and Middle rivers net flow is upstream year-round because of South Delta SWP and CVP export pumping. Tidal flows dominate through most of the Delta and are particularly high in the West Delta. Net flows are greatest where the rivers enter the Delta. (Source: Satellite image courtesy of NASA Landsat Program, http://landsat.gsfc.nasa.gov/. Monitoring data depicted was provided by the United States Geological Survey. The sizes of the arrows are for illustration purposes only.)

Natural estuarine variability and complexity promote abundance, diversity, and persistence of species. Elements of this variability and complexity include predictable and random disturbances, timing and extent of resource availability, and the degree of connectivity among habitat patches relative to the ability of each species to move between them. Dynamic landscapes such as estuaries (in contrast to stable landscapes like agricultural fields) are inherently unstable in their configurations over time and space because different controlling processes operate and interact at different scales of space and time. These environmental fluctuations are what make resources available to a shifting array of species. The resulting variability and complexity in water quality conditions and estuarine geometry is what supports such a broad range of species, high overall productivity, and high abundances of desired species (Moyle et al., 2010).

Salinity and its variability is a key indicator because of its direct importance to a wide range of species, because other important physical and chemical attributes of the aquatic environment mostly track salinity, including water residence times, temperature, turbidity, and organism composition, and because it is of such great interest to societal water uses. The factors of salinity variability that pertain to the desired ecosystem functions for the Delta and Suisun Marsh are (1) magnitude (amount) of gradient change, (2) duration (persistence in time of shifts in gradients), (3) timing (when and where those changes occur), (4) frequency (reliability of changes on tidal, seasonal, and interannual time scales), (5) rates of change (how fast changes occur), and (6) downstream spatial gradient (salinity changes from the river mouths to the lower estuary) (Poff et al., 1997, as cited in Moyle et al., 2010).

River flows are an important component of establishing natural estuarine ecological processes. Important river flow attributes are frequency, timing, duration, and rate of change in flows, occurrence of high flows that can overtop banks to inundate floodplains, and spatial variability in where flows enter the estuary. It is important to recognize that freshwater flows are small compared to tidal flows (Figure 3-2) yet critical to estuarine ecology. The role of river flows in transport, mixing, and habitat creation and maintenance are controlled in large part by the geometry of the waterways and they affect floodplain activation, in-Delta net flows and transport, and Delta outflows. Native species evolved under these natural conditions of estuarine variability and habitat complexity.

Figure 3-2
Tidal Flows from Carquinez Straits Upstream
Note that tidal energy diminishes as moving up into the Delta but still remains quite strong.
Source: Jon Burau, USGS



Today's Delta, in most all respects, is completely unlike its historical condition and unlike most any natural estuary around the world. Humans have completely altered the geometry of the estuary through diking the wetlands and floodplains, connecting most all waterways and converting them into levee-bounded navigation and conveyance canals, changing flow regimes to move Sacramento and San Joaquin river water south to the South Delta export pumps, regulating Delta salinity to be as uniform and low as possible, using dams as a major engineering controls, and loading the waters with agricultural, urban, and industrial waste discharges. The result is a high degree of uniformity (i.e., very low variability), a significant reduction in complexity, frequent shifts of the salinity gradient away from the down-estuary natural state, and degraded water quality. The Delta of today most closely resembles a tidally varying freshwater lagoon.

Section 4
The Decline of the Delta and Suisun Ecosystem

This section describes how changes have resulted in today's degraded ecological functions of the Delta in particular and Suisun Marsh to a lesser extent. This section is structured to describe the human modifications to the system, both within and external to the Delta and Suisun Marsh, the consequent stressors to the ecosystem those modifications caused, and the resulting indicators of degraded ecosystem function that can be measured today. The most important take-home message of this section is that the each of the ecosystem stressors stems from many of the human modifications undertaken over the past 150 years and each of the indicators of poor ecosystem function stem from many of the ecosystem stressors. In other words, the problems seen today are intricately linked across multiple causative factors and thus improving ecosystem function will require a broad spectrum of efforts addressing the full range of stressors.

Relationships between Human Modifications, Ecosystem Stressors, and Indicators of Poor Ecosystem Function

The nature of the poor ecosystem functions observed today in the Delta and, to a lesser extent, Suisun Marsh stems from the full range of human modifications within and external to the Delta and Suisun Marsh and the consequent stressors those modifications have brought. Human modifications to the system are those direct and indirect changes to the landscape that humans have made since European arrival to the region and most critically since the gold rush and statehood in 1850. Ecosystem stressors are the processes and mechanisms that control or "drive" ecosystem functions that these human modifications have brought about. Indicators of poor ecosystem function are those attributes of the ecosystem that can be measured today in the Delta and Suisun Marsh with sampling programs, often referred to as "status and trends monitoring."

Table 4-1 illustrates the relationships between the human modifications and the stressors, and Table 4-2 illustrates the relationships between those stressors and the indicators. The primary message from these two tables is the underlying causes of the problems observed today are complex and interconnected.

Table 4-1
Indicators and Drivers of Poor Ecosystem Function

Human Modifications	**Affected Stressors Driving Poor Ecosystem Function**										
	Physical habitat loss	Flow-related habitat loss	Connectivity and interface loss	Harmful invasive species	Altered flow regimes	Altered Delta geometry	Altered sediment supply	Low residence time variability	Low salinity variability	Entrainment	Contaminant and nutrient loading
1) Wetland and floodplain reclamation	✓	✓	✓	✓	✓	✓		✓	✓		
2) Dams		✓	✓	✓	✓		✓	✓	✓		
3) Channel widening, deepening, straightening for flood control and navigation	✓	✓	✓	✓	✓	✓	✓	✓	✓		
4) Hydraulic mining debris loading	✓					✓	✓				✓
5) Upstream diversions		✓		✓	✓			✓	✓	✓	
6) In-Delta diversions		✓		✓	✓	✓		✓	✓	✓	
7) Delta exports		✓		✓	✓	✓	✓	✓	✓	✓	✓
8) Channel reconfiguration for conveyance and navigation	✓	✓	✓	✓	✓	✓	✓	✓	✓		
9) Discharges from agriculture, wastewater, industry				✓			✓				✓
10) Species introductions for recreation, biological control, accidental	✓		✓	✓			✓				✓

Table 4-2
Relationship between Ecosystem Stressors and Indicators of Poor Ecosystem Function

Indicators of Poor Ecosystem Function	Stressors Driving Poor Ecosystem Function										
	Physical habitat loss	Flow-related habitat loss	Connectivity and interface loss	Harmful invasive species	Altered flow regimes	Altered Delta geometry	Altered sediment supply	Low residence time variability	Low salinity variability	Entrainment	Contaminant and nutrient loading
1) Population decline	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2) Impaired food web productivity and dynamics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3) Low variability in the aquatic environment	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
4) Minimal and uniform habitats and poor connectivity	✓	✓	✓	✓	✓	✓	✓	✓	✓		
5) Poor transit corridor for migratory fish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6) Poor water quality	✓	✓	✓		✓	✓	✓	✓	✓		✓

Recognizing crucial drivers and indicators of poor ecosystem performance is important, because strategies and actions to achieve desired ecosystem characteristics (i.e., ecosystem restoration) should be aimed at those underlying drivers of poor ecosystem function that can be manipulated with direct human intervention, recognizing that some interventions may be difficult to implement.

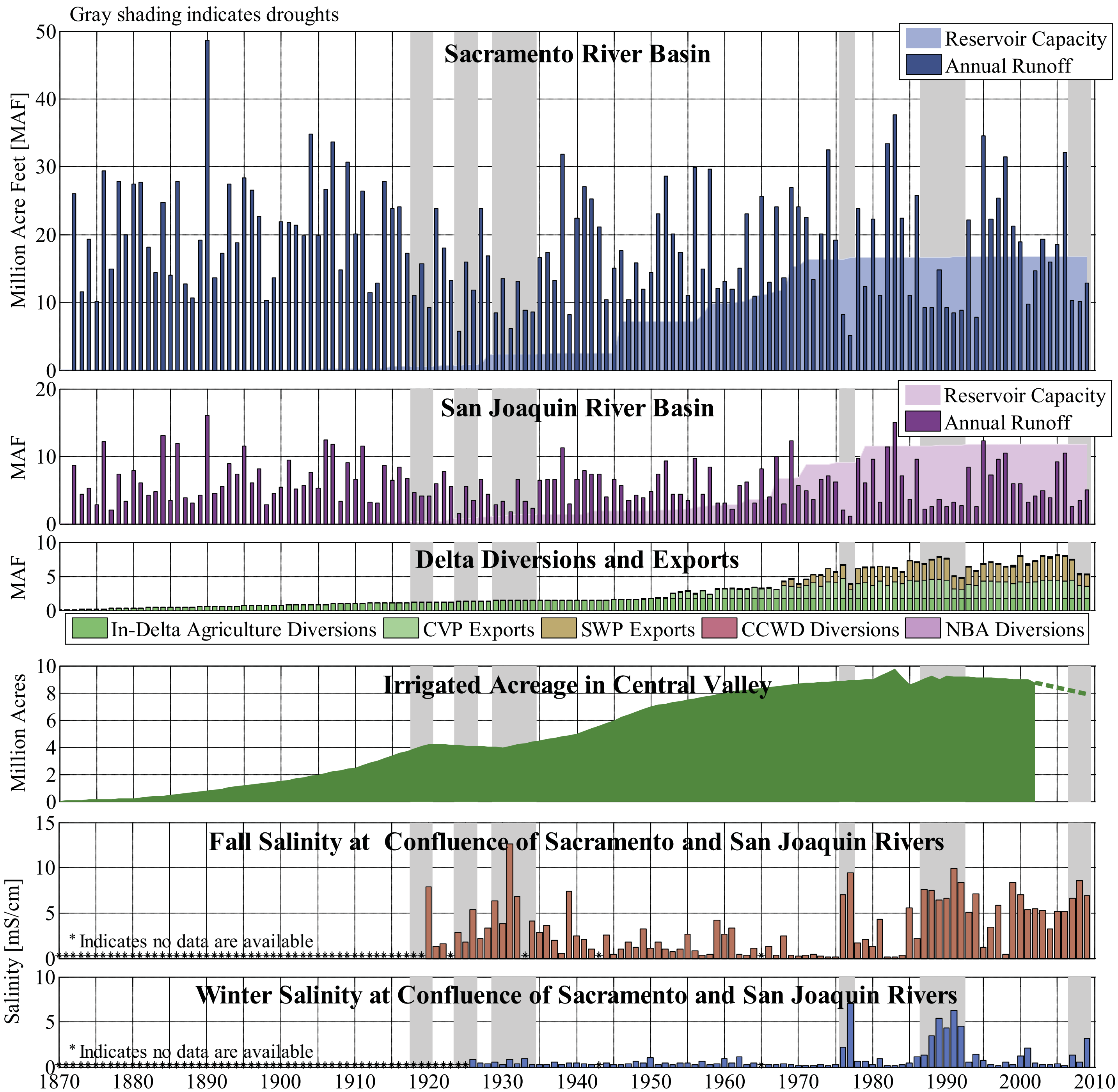
Human Modifications to the Delta and Suisun: How the Delta Became Degraded Ecologically

This section provides brief overviews of the major categories of human modifications that underlie the range of ecosystem stressors and consequent indicators of poor ecosystem function. These categories of human modification are:

1. Wetland and floodplain reclamation
2. Dams
3. Channel reconfiguration
4. Hydraulic mining
5. Upstream diversions
6. In-Delta diversions and Delta exports
7. Agricultural, industrial, and urban discharges
8. Species introductions

To provide a broad initial context, Figure 4-1 illustrates the timeline of key changes to the system.

Figure 4-1
Timeline of Major Changes to the Delta and its Watershed: Dam Construction, Diversions, Irrigated Agriculture
Note the onset of reservoir storage with the Central Valley Project and State Water Project, the increase in diversions upstream and within the Delta and Delta exports. Note also the increase in irrigated agriculture in the Central Valley, placing a high demand on water resources.
Sources: Contra Costa Water District, 2010 (see CCWD 2010 for specific data sources for each plot).



Wetland and Floodplain Reclamation

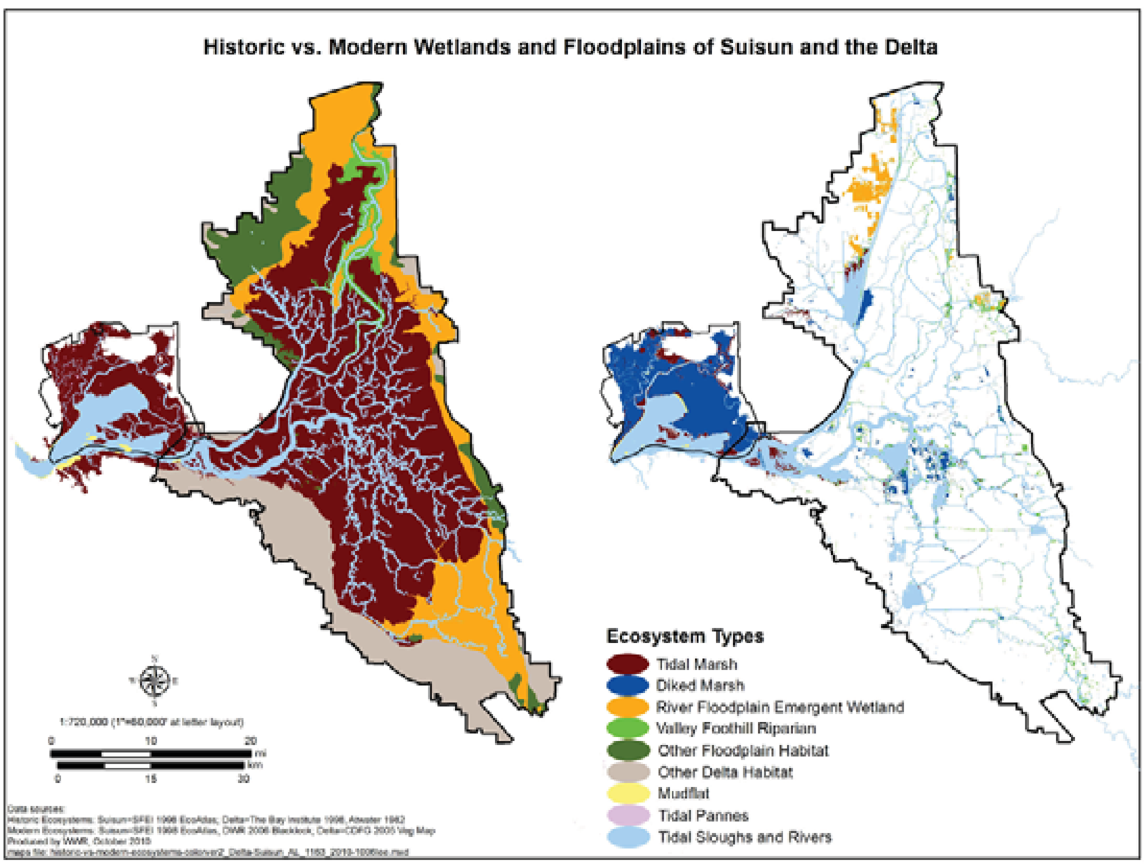
Reclamation of the wetlands of the Delta for agriculture began in the 1850s. Levees were built around tidal marshes, and the marshes were drained, cultivated, and planted for agricultural use. Nearby uplands and seasonal wetlands (e.g., grasslands, vernal pools, and floodplains) were also cultivated for agriculture. By 1900, over half the area of the Delta (235,000 acres) was leveed and reclaimed for agriculture, including 166,000 acres of wetlands (CDPW, 1931, in Bay Institute, 1998). In 1930, the reclamation process was completed with 313,000 acres of former wetlands put behind levees and drained (SFEP, 1991; Bay Institute, 1998). The Delta's watershed has also seen large-scale urbanization, especially within the Central Valley, where many lands originally converted to agricultural use have since become urban developments. As a result of land conversion and flood control, 95 percent of the historical tidal marsh in the Delta has been lost (Figure 4-2). Floodplain and riparian habitats within and upstream of the Delta have suffered similar fates, especially in the Cache Slough area in the northwest Delta (Figure 4-3).

Figure 4-2

Then and Now: Historic and Modern Distribution of Aquatic, Wetland, and Floodplain Ecosystems of the Delta and Suisun Marsh

These schematics of the Delta and Suisun Marsh circa 1850 (left) and at present (right) show the vast land conversions that have occurred since Statehood.

Sources: The Bay Institute, 1998, reprinted with permission (historical Delta); Brian Atwater (historical Delta waterways); San Francisco Estuary Institute Bay EcoAtlas as updated by Wetlands and Water Resources (historical and modern Suisun); Department of Fish and Game 2005 (modern Delta vegetation). Map by Wetlands and Water Resources, 2010.



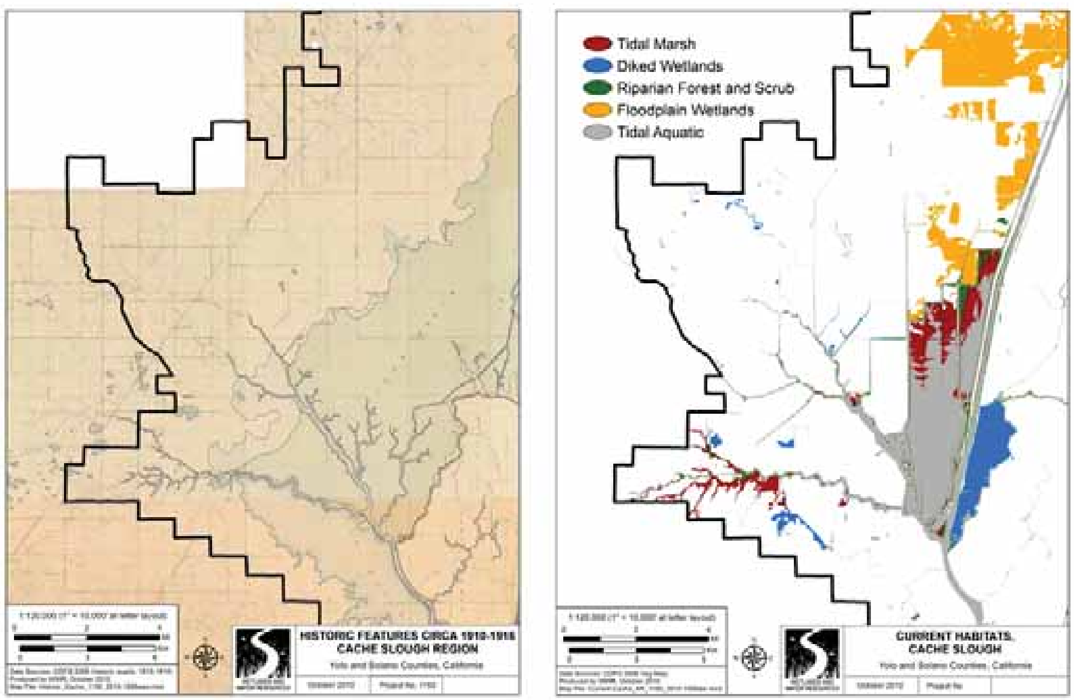
Artificial levees for flood control and land reclamation effectively channelized river systems and hydrologically disconnected tidal and nontidal marsh, riparian forest, and seasonal floodplains from the channels, resulting in large wetland and floodplain habitat losses. In Suisun Marsh, land conversion took a different turn. Most intertidal wetlands were diked to be used for farming, and livestock grazing starting around 1860; however, due to subsidence and increasing salinity, most were converted to managed nontidal marsh and open water habitat for waterfowl hunting by about 1930 (DWR, 1999). The nature of the interface between aquatic and terrestrial ecosystem components in much of the Delta and Suisun Marsh has thus changed dramatically with the historical land use conversion from tidal marshes and floodplains to leveed agricultural and urban lands.

Figure 4-3

Then and Now: Habitats of Cache Slough in 1910-1916 and Current

These simplified schematics of the Cache Slough area of the Delta in 1910-1918 (left) and 2005 (right) show land conversion that has occurred over the past 100 years

Source: Historical maps digitized by DFG. Modern map based on DFG 2005 Delta Vegetation Data. Maps by Wetlands and Water Resources, 2010.



Similarly, grasslands, vernal pools, alkali seasonal wetlands, and other floodplain habitats have been lost to land conversion associated with urbanization and agriculture. The remaining vernal pool landscape in the northeast Delta has been affected by leveling for agricultural land uses (e.g., some grasslands that are currently on the Stone Lakes National Wildlife Refuge). The alkali grasslands and seasonal wetlands in the southwest Delta have been fragmented by agricultural and residential development and by water management projects. Only very limited habitat remains for specialized native vernal pool species, such as fairy shrimp and native vernal pool plants, and many of these are rare, threatened, or endangered today. The most significant relatively intact vernal pool complex is on the Jepson Prairie between Suisun Marsh and the Cache Slough region in the northwest Delta. Seasonally inundated floodplains historically provided essential rearing and foraging habitat for many fish, including splittail and juvenile salmonids, and approximately 460 square miles of historical Central Valley floodplains in the Delta watershed have been hydrologically isolated due to levee construction for flood control, and no longer become seasonally inundated (Culberson et al., 2008; Bay Institute, 1998).

Wetland and floodplain reclamation has contributed significantly to four major stressors to the ecosystem: (1) loss of habitats for a wide variety of species; (2) major land subsidence on diked lands that causes significant modern challenges including levee maintenance and guidance on what lands might be suitable for a range of ecosystem recovery options (Figure 4-4); (3) in combination with channel deepening, widening, and straightening, an increase in tidal range in the Delta; and, (4) in combination with upstream water diversions, tidal energy moving salt up the estuary farther during dry periods.

All of these land conversion losses have eliminated foraging, breeding, and refuge habitats for native wildlife and fish species; have eliminated areas for native plants; eliminated important ecosystem functions that benefit wildlife and humans; and created undue reliance upon the remaining functioning habitats of the Delta.

The most significant effect on the landscape due to large-scale wetland reclamation has been major land subsidence. Subsidence occurs when the drained marshland peat soils are exposed to the air. Lands that were at or near sea level prior to reclamation have currently subsided to elevations well below sea level (up to over 15 feet in the Delta) and will continue to subside with time (Figure 4-5). The agricultural islands are maintained by systems of precarious artificial levees (Moore and Shlemon, 2008). If and when these levees fail (as they have at Frank's Tract and Mildred Island, for example), deep artificial open water "lakes" are created that are far too deep to support marsh vegetation, and which often provide prime habitat for nonnative species, such as Brazilian waterweed and largemouth bass (Kimmerer et al., 2008; Nobriga, 2008; Grimaldo et al., 2004).

Dams

Currently, almost all major rivers and tributaries in the Delta watershed are dammed. Dam construction began in the early 20th century with the large-capacity reservoirs including Shasta (4.5 million acre feet [MAF], 1945), Oroville (3.5 MAF, 1968), New Melones (2.4 MAF, 1979), San Luis (2 MAF, 1967), and others. Dams serve to provide water supply storage, flood protection, and recreation. Dams regulate river flows, converting natural runoff regimes that were seasonally variable into ones with reduced winter and spring flows and increased summer and fall flows. The frequency and magnitude of flood flows has also decreased significantly as the result of water management projects. Dams retain sediment, leading to long-term declines in sediment supply to the Delta, Suisun Marsh, and lower San Francisco Estuary.

Variability in the flow regime and seasonal flooding were historically important drivers of ecosystem structure and processes in the Delta; native plant and animal species evolved under flow regimes of high inter- and intra-annual variability that differ strongly from the current managed regime. Water storage and flow control have dampened such variability across seasons and years, which has greatly changed estuarine hydrodynamics, circulation patterns and nutrient exchanges, and impacted resident species adapted to this natural variability. For example, periodic flood flows would historically regularly "flush" the estuary with freshwater.

Flood flows seasonally inundated floodplains, caused river channel migration and vegetation succession, and added to habitat complexity and productivity as described previously. Flood and floodplain-dependent species including the Sacramento splittail and some salmonids, have been declining in abundance, due in part to alteration of natural Delta flows (Kimmerer et al., 2008). Furthermore, the capture of sediment by dams reduces sediment supplies into the estuary and deprives the Delta of the material needed for restoring intertidal land elevations, replacing sediment lost to erosion along river channels and mudflats, and modifying benthic (river bottom) habitat (Bay Institute, 1998).

Figure 4-4
Land Subsidence in the Delta and Suisun Marsh
Source: 2005 DWR LiDAR with 1.5-ft vegetation adjustment in Suisun Marsh by DWR. Map by Wetlands and Water Resources, 2010.

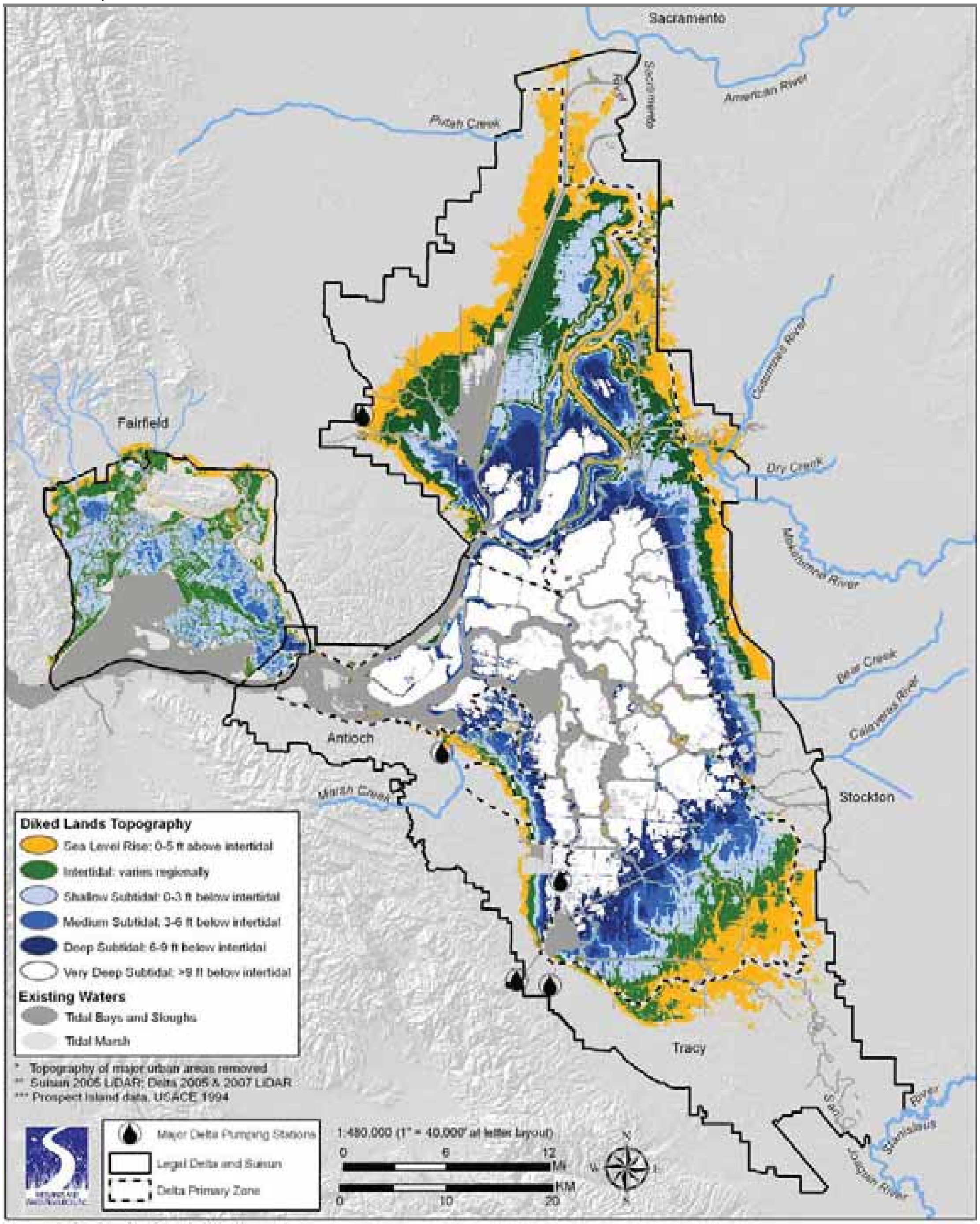
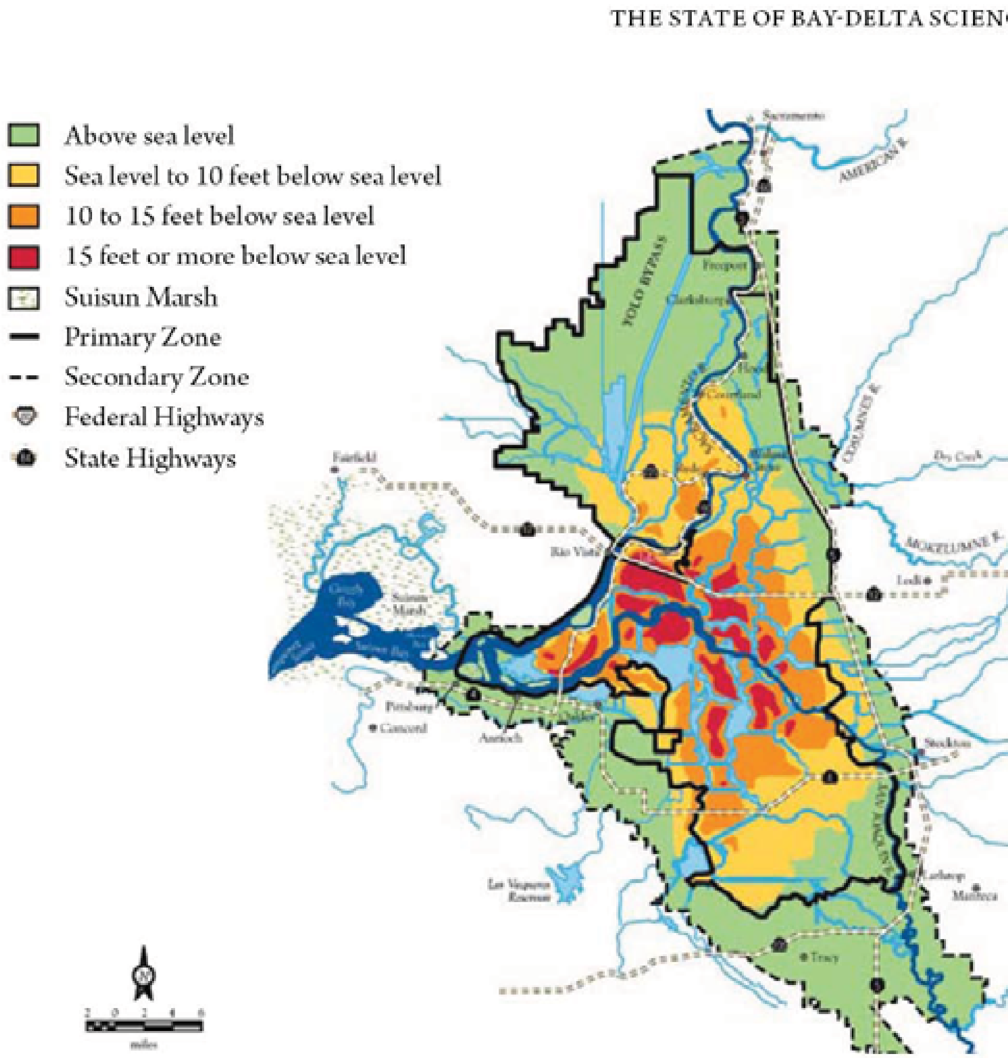


Figure 4-5
Current Delta Topography Showing Effects of Land Subsidence
Source: Lund et al. 2007.

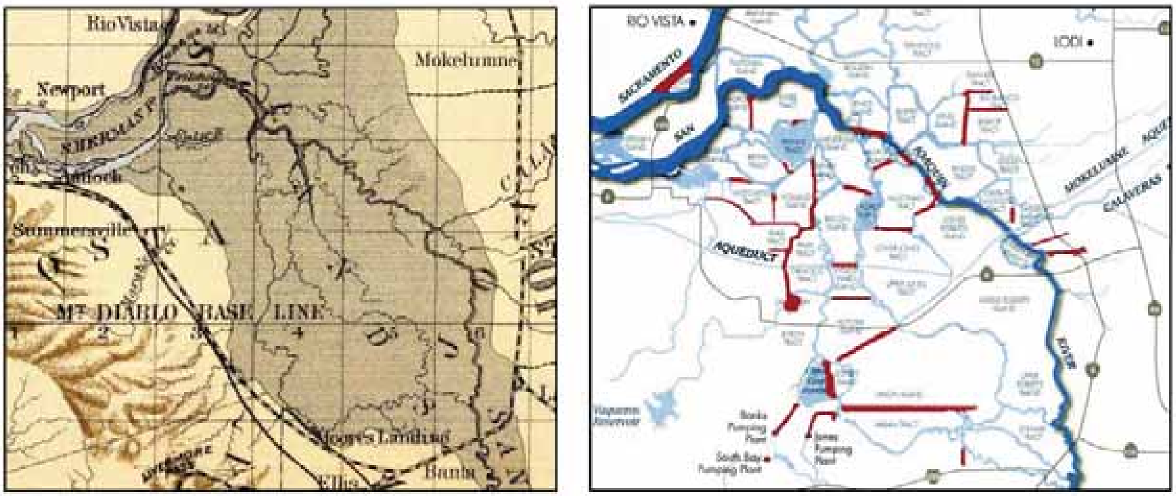


Channel Reconfiguration

Historically, the Delta contained major rivers and sloughs as well as branching (dendritic), dead-end, channel networks connected to their adjacent floodplains and marshes. This geometry provided high diversity in water residence times and general patterns of seaward gradients in salinity and other water quality parameters, which were critical for high levels of primary production, nutrient cycling, and other ecological processes. Flood control, navigation, and the need for conveyance to the south Delta export facilities drove major efforts to widen, deepen, straighten, and connect the Delta’s waterways. Land conversion and flood control eliminated much of the channel network and removed marshes and floodplains. Dredging new waterways for navigation and conveyance connected most remaining waterways (Figure 4-6). Today, the Delta consists almost entirely of interconnected, levee-confined conveyance canals. These changes have greatly homogenized the aquatic ecosystem, by greatly reducing variability, thereby affecting every major ecological process, such as primary productivity, nutrient cycling and transport, habitat and flow variability, and habitat partitioning among species.

Together with simplified waterway configurations, regulation of flow regimes for Delta exports (see below) has reduced variability in water residence time, and led to a reduction in primary and secondary productivity, connectivity, turbidity, and salinity, which together reduce ecosystem complexity to the detriment of nearly all native species and yet benefit many nonnative invasive species (CALFED, 2000; Healey 2008).

Figure 4-6
Then and Now: The Delta's Waterways
These simplified schematics of Delta waterways in 1873 (left) and 1995 (right) show the channelization and reconfiguration of Delta waterways, particularly manmade canals.
Source: 1873 map of unknown origin. 1995 map from DWR Delta Atlas, with constructed waterways highlighted in red from the source.



Hydraulic Mining

Gold mining in the Sierra Nevada began employing hydraulic mining techniques in 1853 and continued these methods until the Sawyer decision in 1884 put an effective end to the practice. Hydraulic mining consisted of blasting large volumes of very high pressure water against the placer gravel deposits to wash away the mountainsides to extract gold deposits. The effect of this practice over its 30 years was to wash away roughly two billion cubic yards of sediment from the mountains, which the streams and rivers carried downstream. The coarser fraction remained in the foothills and the finer fraction, silts and clays, was carried down to San Francisco Bay by the Sacramento and San Joaquin rivers. Approximately 70 percent of the two billion cubic yards of sediment washed into the estuary (Gilbert, 1917, as cited in Jaffe et al. 2007).

Hydraulic mining had two major effects on the Delta and Suisun Marsh. First, it increased sedimentation in waterways and shallow bays from the Sierra Nevada down into the Estuary, In the Central Valley, aggraded channels greatly exacerbated flood problems, which became a major driver in developing comprehensive flood control programs. The federal Sacramento River Flood Control Project included straightening of the Sacramento River, construction of flood control levees, and the establishment of the Yolo Bypass and other Sacramento Valley flood bypasses. In the estuary, the sediment filled in bays and sloughs, creating new marsh from the shallow bays and reducing the overall tidal volume of the estuary.

The second major effect of the hydraulic mining debris was to distribute mercury throughout the entire watershed and estuary. Mercury mined primarily from the coast range was used in gold mining operations to separate out the gold. Mercury is a particularly problematic contaminant in the Delta, and is pervasive in Delta and Suisun Marsh sediments. Enormous quantities of mercury-laden sediment from hydraulic gold mining washed down the rivers in the latter half of the nineteenth century, and smaller doses of mercury continue to dribble downstream from abandoned mercury and gold mines in the Coast Ranges and Sierra Nevada (Bay Institute, 1998; Luoma et al., 2008; Alpers et al., 2008). The mercury that is present in Delta sediments is predominantly inorganic and not bioavailable, but methylating bacteria (which are particularly abundant in environments that wet and dry over prolonged periods, such as on seasonal floodplains and in some wetland environments) convert inorganic mercury to methylmercury, a bioavailable form which is highly toxic to fish, wildlife, and humans. Methylmercury has greatest toxicity effects on species higher in the food chain due to bioaccumulation and biomagnification across trophic levels. For this reason, people are advised to avoid or minimize consumption of certain Delta fish, such as striped bass. Some research suggests that wetland restoration may increase mercury methylation, but this potential is likely dependent on site characteristics and more research is needed (Alpers, 2008).

Upstream Diversions

Major water diversions for municipal, mining, and agricultural uses beginning in the 1850s soon led to increased salinity intrusion into the Delta during dry seasons and drought years. Salinity intrusion was further exacerbated by increases in tidal fluctuations due to channelization and loss of intertidal wetlands. Salinity intrusion peaked in the 1920s and 1930s, and saline waters reached as far inland as Stockton and Courtland in 1931 (DWR, 1995). These unnatural salinity intrusions greatly impacted human communities, natural habitats, and agricultural areas in the Delta. Water storage and flooding concerns also increased with land reclamation and urban and agricultural development. Upstream dams and reservoirs were thus built for water storage, flood control, and freshwater flow regulation beginning in the 1920s, with Friant Dam completed on the San Joaquin River in 1941 and Shasta Dam completed on the Sacramento River in 1944.

In-Delta Diversions and Delta Exports

Major water diversions and exports from the Delta began with the California Gold Rush, but the Delta effectively became the hub for California water redistribution between 1920 and 1970, during which time comprehensive water management systems were put into place (Healey et al., 2008). Flows through the Delta are now highly regulated because of upstream storage needs, flood control, maintenance of Delta water quality, and conveyance of water supplies to over two-thirds of the California population. These water management systems collectively represent a significant set of controls on the Delta’s aquatic ecosystems, dampening natural variability in physical processes and altering several fundamental ecosystem processes.

Water diversions from the Delta cause changes in the complex flow dynamics in the Delta, which unnaturally affect migration and movement of fish and other aquatic organisms, limit access to suitable habitats, and alter water quality. The two largest water export facilities in the Delta are part of the federal CVP, which began exports in the early 1950s, and the SWP which began exports in the late 1960s (Healey, 2008). Both export facilities are located in the south Delta. Together, pumping from these export facilities can effectively reverse flows in Old and Middle rivers (Figure 4-7, Bay Institute, 1998; DWR 1995; DFG, 2008). Other water diversions and consumptive water use within the Delta (over 2,000 diversions) total an additional 1.7 million acre-feet (DWR 1995; Bay Institute, 1998; Culberson et al., 2008; Herren and Kawasaki, 2001).

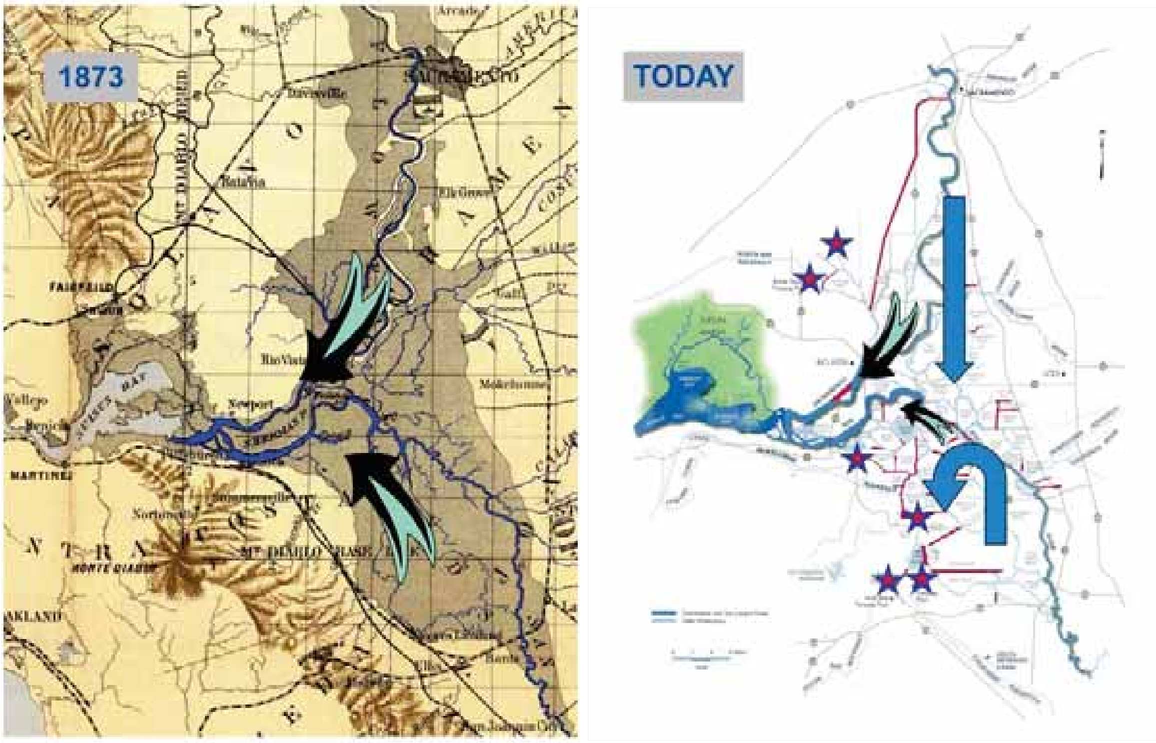
Water diversions cause direct mortality (entrainment and stranding) of fish and other aquatic organisms. Many larger diversions are screened to reduce these impacts, but effectiveness of screens depends on design, site-specific conditions, and maintenance (CALFED, 2000). Smaller diversions for local agricultural irrigations (of which there are approximately 2,200 in the Delta) are often unscreened, leading to stranding and losses of fish and other aquatic organisms (Herren and Kawasaki, 2001; CALFED, 2000).

Figure 4-7

Then and Now: Major Modifications to Delta Flow Regimes

These simplified schematics show how conversion of the Delta to a water conveyance corridor has caused major Delta flow patterns to change, the most fundamental being (a) redirection of part of Sacramento River flows south to the export pumps, (b) reversal of much of the San Joaquin River flows south to the export pumps through Old and Middle rivers, (c) large reduction in net Delta outflow during the winter and spring, and (d) small increase in net Delta outflow in the summer and fall (to maintain freshwater conditions in the Delta)

Source: Historic map of 1873 unknown source. Modern map base from DWR Delta Atlas, 1995. Maps prepared by Wetlands and Water Resources, 2008.



Groundwater is also used extensively by agriculture and municipal users in the Delta. The Delta is located primarily over the western portions of the Sacramento Valley and San Joaquin Valley groundwater basins. It is not known how much groundwater is pumped out of the Delta, but as of 1989, it was estimated that there were about 100,000 groundwater pumps operating in the greater Central Valley (Williamson et al., 1989, in Bay Institute, 1998). During dry years, as much as half of the water supply for the Central Valley may be derived from groundwater (Bay Institute, 1998). Groundwater pumping has led to major changes in groundwater hydrology, at least in portions of the valley. Instead of much of the Central Valley being a groundwater discharge area, the valley is now primarily a groundwater recharge area (groundwater discharge occurs generally as a result of pumping diversions rather than natural seepage into wetlands), particularly in the San Joaquin Valley (Healey, 2008). This reduces surface water supply, and also causes salts and selenium to accumulate in the soils, in turn, increasing contaminants in agricultural runoff (Healy et al., 2008).

Agricultural, Industrial, and Urban Discharges

Agricultural and urban areas contribute large quantities of pesticides to the Delta watershed. Pesticides were widely adopted into agricultural practices during World War II, and concentrations of highly toxic organochlorine pesticides (such as DDT) in the Delta increased greatly after about 1950, resulting in massive mortality to fish and wildlife and birds (Bay Institute, 1998). These highly toxic and persistent pesticides were mostly banned or phased out by the 1980s, but residues of these pesticides remain in

Delta sediments, and elevated concentrations of these chemicals are sometimes found in aquatic organisms of the Delta, including fish (Bay Institute, 1998; Smalling et al., 2007). Pesticides applied in recent decades (for example, organophosphates and carbamates) have also produced toxins in the system and new types of pesticides are constantly introduced for use in the Delta watershed. Selenium is another major contaminant of some agricultural runoff, particularly in the San Joaquin Valley where salt and selenium have concentrated in the soils due to continued irrigation and changes in groundwater hydrology, causing reproductive toxicity for many fish and wildlife species (Luoma et al., 2008). Urban runoff contributes additional toxic pesticides to the watershed, as well as nutrients, pathogens, hydrocarbons, and metals such as mercury, copper, lead, and zinc (Bay Institute, 1998; SFEI 2010). Similarly, nutrients entering the watershed from agricultural runoff or from municipal wastewater treatment plants may negatively affect ecosystem dynamics and cause localized toxicity to aquatic organisms (Werner et al., 2008).

Species Introductions

The Bay-Delta watershed has been altered by the deliberate and accidental introductions of hundreds of nonnative species over the past 160 years (Bay Institute, 1998). Nonnative invasive species that act as keystone species – playing a vital role in shaping the natural environment – present the greatest ecosystem impacts. Several such invasive species severely restrict the ability to improve the Delta's natural resources. Brazilian waterweed, water hyacinth, overbite clam, and Asian clam are four of the most significant keystone species currently affecting the Delta's ecosystem. They alter habitat suitability, consume vast quantities of primary and secondary production, and alter species composition and food web structure.

A large variety of nonnative fishes was intentionally introduced to the ecosystem by the California and U.S. Fish Commissions in the late 1800s (Dill and Cardone, 1997). The modern fish fauna of the Delta consists of 58 species, approximately 30 of which are nonnative, including striped bass, various catfish species, and threadfin shad, which compete with and in some cases have completely displaced native resident fishes of this ecosystem (Herbold and Moyle, 1989; Bay Institute, 1998). Benthic (river bottom) communities are also dominated by nonnative filter feeders (e.g., Asian clam), which were mostly introduced in ballast water (Bay Institute, 1998). Numerous invasive aquatic and terrestrial plants have likewise been introduced to Delta ecosystems, many of which were originally imported for horticulture or landscaping use. In some cases these invasive plants significantly modify habitat structure and function for native species (e.g. Brazilian waterweed, giant reed).

Stressors: Drivers of Poor Ecosystem Functions

The suite of human modifications to the Delta, Suisun Marsh, and the watershed described above act individually and in combination to modify physical, chemical, and biological processes and mechanisms within the Delta and Suisun such that they act as *stressors* adversely affecting desired ecosystem functions. A common theme across all these stressors is their role in simplifying the Delta system in many ways (see Section 3) and in turn *driving,* or resulting in, poor ecosystem functions. This section presents a description of the following stressors that drive poor ecosystem functions in the Delta and Suisun Marsh:

- Physical habitat loss
- Flow-related habitat loss
- Connectivity and interface loss
- Harmful invasive species
- Altered flow regimes
- Altered geometry
- Altered sediment supply

- Low residence time variability
- Low salinity variability
- Entrainment
- Contaminants
- Nitrogen loading
- Other water quality issues
- Harvest
- Hatcheries

Physical Habitat Loss

Throughout the Delta, most historical habitat for native species has been lost due to land conversion to agricultural and urban land uses, flood control and water management projects. As discussed previously and illustrated in Figure 4-2, over 95 percent of the historical tidal wetlands in the Delta were diked and drained for land reclamation or otherwise lost over the past 150 years. The result of these major land modifications is that only small, remnant fragments of tidal and nontidal wetlands, riparian forest, grasslands, seasonal wetlands, and other floodplain habitats remain today. In Suisun Marsh, most intertidal wetlands were diked and ultimately converted to managed nontidal marsh and open water habitat for waterfowl hunting. The elimination of the tidal marshes removed an important moderating mechanism of water quality and food web productivity. By eliminating overbank flooding of tidal marshes, the exchange of organisms, detritus, nutrients, and sediment with the aquatic environment is eliminated, removing an important element of estuarine productivity. In addition, the channel flushing effect when spring tides flood marsh plains has been lost as tidal marshes were lost.

Substantial physical habitat losses cause reductions in regional carrying capacities for the wide array of native species depending on those habitats; in other words, reductions in habitat area within the region result in reductions in the species' population sizes that can potentially be supported. These reductions in population carrying capacities in turn greatly increase the susceptibility of native species to local extirpation or extinction. Physical habitat loss also results in habitat fragmentation, which can disrupt species' movements necessary to support breeding, foraging, migration, and dispersal, while also potentially reducing genetic exchange among populations occupying different habitat areas and increasing vulnerability of populations to random disruptive events. However, sometimes one species' loss is another species' gain: For example, conversion of tidal marsh to diked, managed wetlands in Suisun Marsh and other locations may have resulted in a loss of habitat for some species (e.g., fish), but may also have resulted in a gain in habitat for waterfowl species. Similarly, reclaimed agricultural lands currently provide important habitat for certain native species that have adapted to utilize those resources because their original habitats elsewhere have been lost (e.g., Swainson's hawk, greater sandhill crane).

In general, however, the major land conversion losses that have occurred in the Delta have eliminated foraging, breeding, and refuge habitats for a wide array of native wildlife, fish and plant species; have greatly diminished ecosystem productivity; have eliminated important ecosystem functions that benefit wildlife and humans; and have created undue reliance upon and pressure on the remaining habitats of the Delta.

Flow-Related Habitat Loss

Important river flow attributes are frequency, timing, duration, and rate of change in flows, occurrence of high flows that can overtop banks to inundate floodplains, and spatial variability in where flows enter the estuary. There are many links between freshwater flow and fish responses and the responses are often indirect and are not fully understood. For example, spring flows that bring lower salinities and higher turbidities to the western Delta and Suisun Bay and Marsh provide important cues to the spawning migrations of native fish which may improve their reproductive success. Floodplain inundation produces and exports biologically available carbon, stimulates food web activity from plankton to birds, and provides spawning and rearing habitat for floodplain adapted fish (Richter et al., 1997; Poff et al., 1997; Moyle et al., 2007; Williams et al., 2009). This “floodplain activation” improves feeding and growth of salmon and steelhead smolts (Sommer et al., 2001) and provides rearing habitat for many native estuarine fish species. Compression of the salinity gradient by high freshwater flow causes subtle but important changes that improve retention and increase populations of several species (Jassby et al., 1995; Kimmerer et al., 2009). Export flows cause direct mortality and alter net flows in the south Delta to the detriment of some native fish species.

Flow-related habitat effects in the Delta are poorly understood because linkages between ecosystem responses and net flow involve a number of interacting processes. Water flows are affected by many variables and water motions are dominated by tides in the Delta. Tidal flows vary daily, seasonal flows reduce tidal amplitude and simultaneously reduce flood and increase ebb tidal flows, and Delta gates and diversions substantially redirect tidal flows, creating changes in flow patterns. These changes may influence migratory cues for some fishes; affect transport of nutrients, phytoplankton, eggs, and larvae; and affect water quality through changes in transport, mixing, and dilution. All of these responses depend on the interaction of freshwater and tidal flows with other attributes of the system such as channel configuration and water quality.

Connectivity and Interface Loss

In functional ecosystems, the food web depends upon spatial and temporal transport of constituents and organisms between different habitats. Variability in the aquatic environment provides a mixture of biologic, hydrologic and geochemical conditions that support the development and growth of the different components of the aquatic foodweb (e.g., algae, invertebrates, and fish). Connectivity between the aquatic environment and the land expands the aquatic foodweb to include terrestrial species such as birds, waterfowl, and mammals. Nutrients, micronutrients, ions, sediments and microbes are transported from land surfaces into the aquatic environment. Tidal interactions and tidal exchange directly result in the cycling of water and the constituents and species it carries; and indirectly lead to the movement of fish, invertebrates and other species between habitats in response to the availability of food, changes in cover and other factors. This connectivity between aquatic environments and the surrounding terrestrial environment is important in the development of an ecosystem’s richness and diversity. Channelized rivers, restrictions on tidal exchange, engineered levees which constrain flow and disconnect natural habitats, limits to terrestrial inputs, and reduced surface area between water and land all act to reduce hydraulic retention times, limit soil/water interactions and exchanges, and compromise a wide range of ecosystem processes.

Harmful Invasive Species

The San Francisco Bay Estuary and Delta is one of the most invaded aquatic systems in the world. Recent reports show 193 introduced species (69 plants, 89 invertebrates, and 35 vertebrates) now dominate most habitats within the Delta-Suisun region (DWR, 2007). The effects of most introduced species on the Delta ecosystem are unknown, but those that are invasive spread rapidly, become dominant in their habitats, and displace natives through competition, predation, and foodweb alteration.

Two clams from Asia, overbite clam and Asian clam, dominate the benthos of Suisun Marsh and the Delta, respectively; they alter habitat suitability, consume vast quantities of primary and secondary production, and alter species composition and food web structure (Lund et al., 2007b). Among the many introduced fish in the Delta, threadfin shad and inland silversides are some of the most invasive, although shad abundance has apparently decreased in recent years (DWR, 2007). Striped bass and largemouth bass were deliberately introduced and now are among the most abundant fish of pelagic and nearshore habitats. Bass are predatory and have significant negative effects on native species.

Among invasive plants introduced to the Delta and Suisun, the most visible are the submerged aquatic plant Brazilian waterweed and the floating aquatic plant water hyacinth, which can choke low-velocity channels. Both species have greatly affected the aquatic ecosystem, by creating dense vegetation canopies in the middle and upper portions of the water column (Figure 4-8). This dense vegetation slows and alters the directions of flow, facilitates sediment deposition which reduces turbidity, increases surface water temperatures, and can elevate pH during the day and cause significant declines in dissolved oxygen levels at night. Dense vegetation can also prevent waterfowl access to their benthic food sources (e.g., plants, plant propagules and invertebrates). The introduction of water hyacinth and Brazilian waterweed has greatly reduced habitat quantity and quality for many native fishes: the thick cover of these two invasive plants provides preferred habitat for nonnative predatory fish, such as bass and sunfish that prey on native fishes (Grimaldo et al., 2004; Nobriga, 2008; Kimmerer et al., 2008). In addition, riparian forest habitat has been degraded by invasions by nonnative invasive plants, including tree-of-heaven, giant reed, black locust, and blue gum. These plant species have degraded riparian habitats by outcompeting native plants that provide better canopy cover, host more insects, and provide greater forage value for native wildlife.

Figure 4-8

Water Hyacinth

Water hyacinth is a floating annual invading nonnative plant that can rapidly colonize Delta sloughs. Every year water hyacinth dies back in winter as is shown in this photograph.

Source: AECOM, 2009

Changes to Delta hydrology, particularly those reducing temporal and spatial variability in the aquatic ecosystem, have significantly altered aquatic habitats to the advantage of several invasive species and the detriment of natives (Sommer et al., 2007; Williams, 2006; Lund et al., 2007a; Kimmerer et al., 2008; Moyle et al., 2010). For example, reduced turbidity favors the growth of invasive submerged aquatic vegetation harboring invasive predatory fish (Grimaldo et al., 2004; Kimmerer et al., 2008; Nobriga, 2008), while reduced fluctuations in salinity also favor many invasive nonnative fish to the detriment of native fish (Lund et al., 2007a).

Altered Flow Regimes

Flow in the Delta has been dramatically altered. Historically, flow moved seaward, with seasonal changes in inputs from the San Joaquin and Sacramento rivers as well as the smaller tributaries in response to California's Mediterranean climate and the water storage characteristics of its mountainous areas. Beginning with statehood and continuing well into the late 20th century, humans have engineered California's water network primarily to support agriculture in the rich Central Valley and Delta area and to provide water to the state's growing population. These efforts have resulted in altered flow regimes. Today, Delta flows have a strong north-to-south directionality (to the CVP and SWP South Delta export pumps) and the timing and magnitude of inflows to the Delta are highly regulated to support water supply and salinity requirements. Figure 4-9 illustrates the Delta outflow hydrograph during three time periods of water resource development. There are several important aspects in this figure. First, unimpaired flow exhibits considerable variability across the three time periods, reflecting different climatic regimes. Second, there has been a progressive decrease in the amount of historical Delta outflow relative to unimpaired, reflecting increased diversions and exports. Third, that fall (September and October) historical outflows exceeded the natural unimpaired flows for the first two periods (1949 to 1985), reflecting reservoir releases to keep the Delta fresh. In the most recent period (1986-2003), September outflows were slightly elevated but not as much in prior periods, and October flows were reduced. This change reflects more intensive diversions and exports.

Flows from the San Joaquin have been greatly reduced through diversion for upstream agriculture via its high regulated tributaries of the Merced, Tuolumne, and Stanislaus rivers. San Joaquin flows often do not transit the Delta but instead are "reversed" through Old and Middle rivers to the South Delta export pumps including use of temporary flow barriers in the south Delta. The Sacramento River is the major source of freshwater into the estuary but, like the San Joaquin River, much of its upstream flows are diverted for agricultural use before it reaches the Delta. Once reaching the Delta, seasonally varying proportions of Sacramento River flows are conveyed south to the export pumps via seasonal operation of the Delta Cross Channel and pumping volumes at the South Delta export facilities.

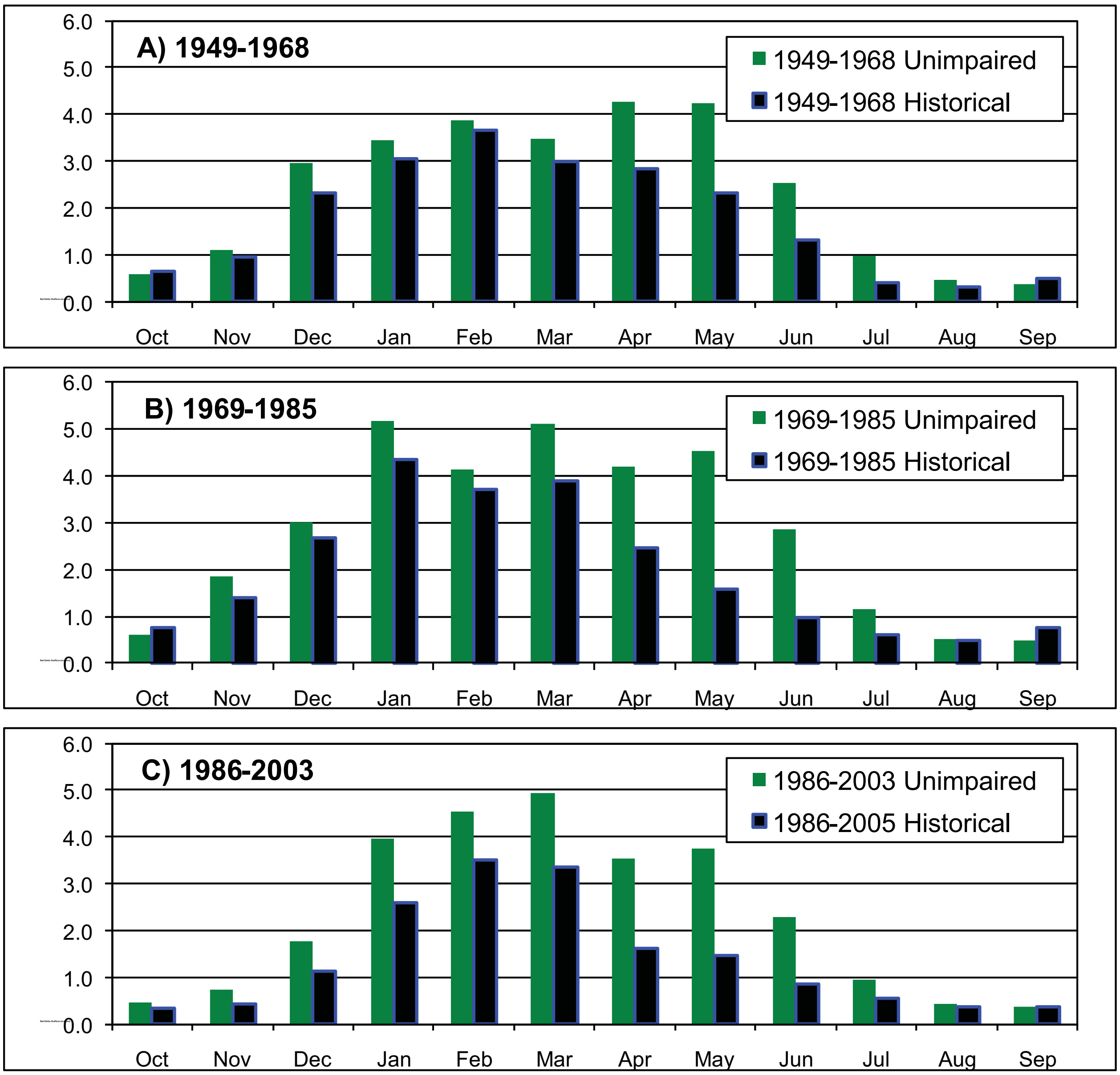
Reservoirs throughout the Central Valley watershed are operated to store water in the winter and spring (while accounting for flood control needs) and release water in the summer and fall to meet agricultural demands and provide for urban and industrial uses. Because these water uses require low salinity water, the Delta is managed as a freshwater system. Releases to support instream fisheries are also a component of reservoir operations, and Delta outflow is also managed to meet salinity targets for Suisun Bay and Marsh.

Figure 4-9

Delta Outflow Hydrographs by Month during Three Periods of Water Resources Development.

Figure 4.9-A shows the period 1949 to 1968, Figure 4.9-B shows the period 1969 to 1985, and Figure 4.9-C shows the period 1986 to 2003. The early 20-year period represents a time when fish were known to be doing better and the last 20-year time frame when fish were doing worse (Moyle and Bennett, 2008). The middle 17 years represents a transitional water export period and contains extreme wet and dry periods. Key changes in these periods were construction of new dams and reservoirs that greatly expanded storage (e.g., Shasta Dam 1945), significant increases in upstream diversions and Delta exports (see Figure 4-1), and increased acreage of irrigated agriculture in the Central Valley.

Source: UC Davis Watershed Science Center, based on DWR data.

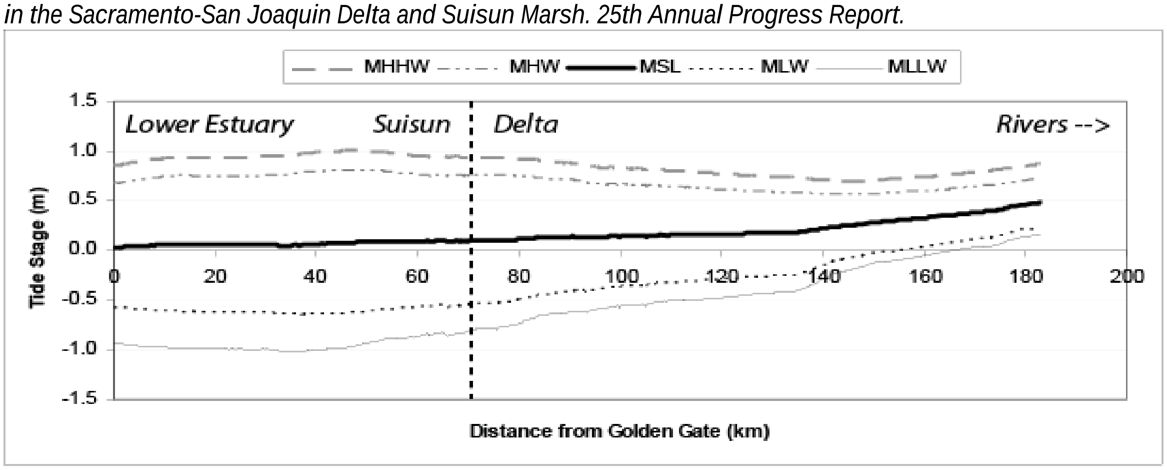


While the tides are powerful enough to create an impression of normal land to seaward movement, the net flow can be overwhelmed by movement of water towards the pumps in the south Delta. This complex and altered hydrologic regime has led to a confusing environment for migratory fish (e.g., outmigrating juvenile salmon may end up in the central and southern Delta, where water temperatures are higher and water quality is otherwise unfavorable) and it draw others, such as delta smelt, toward the south Delta pumps (Kimmerer, 2008; Grimaldo et al., 2009). Current flow conditions favor resident freshwater invasive organisms such as largemouth bass and Brazilian waterweed (Brown and May, 2008; Brown et al., 2009). These altered flow regimes also contribute to low residence time variability and low salinity variability, both discussed below.

Altered Geometry

The geometry of the Delta has been drastically altered. This altered geometry has significant adverse effects on ecosystem functions in the Delta and Suisun Marsh. Altered geometry affects the transmission and dissipation of tidal and river flow energy across the landscape and how tidal and riverine waters mix within the Delta. Today’s geometry does not dissipate tidal energy very effectively, resulting in higher tide ranges further up the mainstem rivers (Figure 4-10; Chris Enright, personal communication, September 2010). The resulting higher energy environments reduce residence times, resulting in less primary and secondary production. The interconnected waterways in combination with the high tidal energy act to keep Delta waters well mixed, leading to low salinity variability, which favors invasive species. Flooded Delta islands and the margins of Delta waterways away from the mainstem rivers provide sheltered areas. While these sheltered areas can provide some residence time variability, some of these areas support Brazilian waterweed that provides habitat for bass and other introduced fish species that prey upon native species. Sheltered waters can also providing the setting to support blooms of toxic blue-green algae (OEHHA, 2008).

Figure 4-10
San Francisco Estuary Tidal Datum Profile (Modeled)
Source: DWR 2004 Development of Tidal Analysis Routines. Chapter 10 in: Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 25th Annual Progress Report.



San Francisco Estuary-California Delta Tidal Datum Profile (modeled). *From DWR 2004*

Altered Sediment Supply

The watershed of the Delta and Suisun Marsh was subject to large scale placer mining from 1853 to 1884, which resulted in transport and deposition of large amounts of sediment in the rivers of the Central Valley. This hydraulic mining debris took about 100 years to work its way through the watershed (TBI, 1989, p.3-23). In the 20th century, major dams and in-channel sand and gravel mining operations on

Central Valley rivers have become sediment traps. Reduction of the hydraulic mining pulse and construction of dams led to a 50 percent reduction in sediment supply from the Sacramento River between 1957 and 2001 (Wright and Schoellhamer, 2004).

Decreasing sediment inputs are one of the factors contributing to a recent trend in increasing water transparency in the Delta, the others being sediment “washout” from very high inflows in 1982-83, and proliferation of large beds of submersed aquatic vegetation that is “filtering” sediment (e.g., Brazilian waterweed) (Nobriga et al., 2008). Delta smelt abundance is negatively correlated to water clarity (Nobriga et al., 2008), and a reduction in turbidity may reduce the feeding efficiency and/or vulnerability to predators of delta smelt.

Low Residence Time Variability

Residence time is a measure of how long water stays in one place. Highly energetic environments have a very short residence time. Strong tides or large river flows mix the water column and move water very rapidly (minutes to hours) over large distances. Calm environments have much longer residence times and can support stratified water columns. Lakes, lagoons, and backwater areas have water that can remain essentially in one place for long periods of time (days, weeks, or longer) (Kimmerer et al., 2008). As described in Section 3 above, the Delta and Suisun historically had a wide range of low to high energy environments connected to one other either seasonally (e.g., floodplain wetlands) or year-round (e.g., tidal marshes) and the complex geometry played a critical role in establishing high variability in residence times through its energy dissipation function. That natural setting produced substantial spatial and seasonal variability in residence times. An estuary that has high spatial variability in residence times is generally considered to be capable of supporting more species and higher productivity (Moyle et al., 2010).

Today the Delta is one big tidally fluctuating freshwater lagoon, well connected and well mixed, resulting in uniform and generally short residence times. Elimination of most of the Delta wetlands, conversion of rivers and sloughs into conveyance canals, constructing waterways to interconnect the remaining Delta waterways, and managing the Delta for consistent low salinity via Delta inflow management have combined to generate a very uniform Delta. The generally low and uniform residence times have reduced water quality variability (salinity and temperature in particular); reduced the magnitude and persistence of phytoplankton blooms essential to the aquatic food web (Moyle et al., 2010); directly simplified the available habitat, favoring a more narrow group of aquatic species commonly associated with temperate freshwater lakes; and helped to support colonization, establishment, and spread of harmful invasive species such as the Asian clam and Brazilian waterweed (Brown et al., 2009).

Suisun Marsh has experienced many but not all of the changes made in the Delta that affect residence time variability. Like the Delta, most of the tidal marshlands of Suisun were lost with levee construction. With that loss went the geometric complexity that affects tidal energy dissipation as well as the structural marsh features with their highly variable water retention time attributes. Unlike the Delta, the remaining waterways of Suisun were, for the most part, not connected to one another via constructed waterways. Therefore, the larger-scale geometric complexity that helps support more variable residence times was retained. Suisun Marsh has a far greater diversity and abundance of native estuarine fishes than the rest of the Delta, in part resulting from its more varied residence times supporting greater ecosystem functions necessary to support those native fishes.

Low Salinity Variability

The Delta of today is managed to keep salinity uniformly low year-round throughout all but the most western extent of the Delta in order to meet salinity needs for in-Delta and exported uses. In-Delta agricultural diversions are the most widespread and numerous and require freshwater throughout the irrigation season (roughly late spring into the fall). South Delta exports for agriculture require the same regime. Public water supplies drawn from the Delta are few in number but are large in demand as they serve 25 million Californians[3]. Exports require freshwater when operating, which is year-round for most facilities. Recently, Delta exports have gone to fill new south-of-Delta reservoirs, with export timing depending upon a variety of factors. This management regime actively seeks to reduce the exact variability essential to estuarine productivity.

How much natural salinity variability the Delta experienced has been a controversial subject. It is known that the expanse of tidal marsh in the historic Delta strongly dissipated tidal energy. By comparison, today's deepened, widened, straightened canals and lack of tidal wetlands means that tidal energy can move much further upstream. Long periods of drought (decades, unlike any experienced in modern times) would presumably have favored extensive movement of salt water farther into the Delta. In modern times, dredging of shipping channels from San Pablo Bay upstream to Sacramento and Stockton greatly facilitates upstream transport of salt (Enright and Culberson, 2009). Upstream freshwater diversions also increase the frequency of saltwater intrusion, especially in drier years.

The vast extent of tidal marshlands and shallow bays spread through the Delta, Suisun Marsh, and San Pablo Bay historically meant that somewhere in the estuary the salinity regime needed by any particular species was most likely present in abundance, even during prolonged droughts or wet periods. Consequently, historic salinity intrusion into the Delta likely did not exert an overwhelming control on native species abundance. Today, the geographic extent of salinity variability is of great importance because the nearly complete elimination of tidal marshlands throughout much of the estuary means that many species have difficulty finding suitable salinity-based habitat conditions for some portion of their life history.

The new low variability salinity regime in the Delta supports an assemblage of primarily nonnative freshwater species that live in fairly clear, fresh water with strong tidal fluxes. Most of the harmful invasive species in the estuary thrive in these highly altered conditions. Such prolonged stabilization, combined with a relatively rapid influx of nonnative species, has caused a regime shift (Scheffer and Carpenter, 2003; Folke et al., 2004) that is also reflected in the overall low and declining productivity of the San Francisco Estuary compared with other estuaries worldwide (Nixon, 1988; Anke Mueller-Solger, CDWR, personal communication) and the apparent loss of resiliency by pelagic fish populations that previously rebounded during periods of favorable environmental conditions (Sommer et al., 2007).

Entrainment

Large numbers of delta smelt and other fish are lost to the CVP and SWP water export facilities located in the south Delta. The risk of entrainment to delta smelt varies seasonally and among years. The greatest entrainment risk has been hypothesized to occur during winter when pre-spawning adults migrate into the Delta in preparation for spawning (Moyle, 2002; USBR, 2004). The direct impacts of water diversions on the overall population dynamics of delta smelt is not well understood and there is disagreement among experts about the magnitude of these impacts (Bennett, 2005). In addition, the CVP and SWP water export facilities and other diversions export phytoplankton, zooplankton, nutrients, and organic material that would otherwise support the base of the food web in the Delta, thus reducing food availability for delta smelt (Jassby and Cloern, 2000; Resources Agency, 2007).

At the SWP and CVP export facilities, multiple factors influence the vulnerability of juvenile salmon and steelhead to entrainment, including the geographic distribution of steelhead within the Delta and hydrodynamic factors, such as reverse flows in Old and Middle rivers. Salmon and steelhead respond behaviorally to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile

[3] http://www.water.ca.gov/swp/swptoday.cfm

migration through the Delta. Changes in these hydraulic cues as a result of SWP and/or CVP export operations during the migration period may contribute to delays in migration, attraction to false migration pathways, or increased movement of migrating salmon and steelhead toward the export facilities, increasing the risk that these fish will be entrained into the fish salvage facilities.

In addition to the CVP and SWP water export facilities located in the south Delta and various smaller facilities, there are about 2,200 agricultural diversions in the Delta (Herren and Kawasaki, 2001). Most of these diversions are not screened to exclude fish. Cook and Buffaloe (1998) found that a large diversity of fish species can be entrained by small agricultural diversions, especially young-of-year fish present from May through August. Since delta smelt spawning and larval development is likely to occur in shallow shoreline locations, entrainment of these life stages by agricultural diversions may be significant.

Unscreened or insufficiently screened intakes can result in the entrainment of juvenile salmonids into agricultural diversions. Many juvenile salmon and steelhead migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels. No quantitative estimates have been developed to assess the potential magnitude of entrainment losses for juvenile salmon and steelhead. The effect of entrainment mortality on the population dynamics and overall adult abundance of salmon and steelhead is not well understood.

Contaminants

Contaminants have been identified as an important stressor and driver of declines in ecosystem function in the Delta and Suisun Marsh. An unknown number of chemicals are introduced into the Delta from a variety of sources. Sources include point sources such as effluents from municipal and industrial wastewater treatment plants, as well as urban, agricultural and industrial nonpoint sources. The fate of contaminants in the estuarine ecosystem is complex, depending on interactions among transport, mixing, and residence times (Kuivila and Hladick, 2008). The types of contaminants thought to be present in the Delta with the potential to affect aquatic and terrestrial species include (Werner et al., 2008):

- Pesticides, both current use and residues of legacy pesticides
- Mercury and other heavy metals such as copper and nickel
- Selenium
- Polychlorinated biphenyls (PCBs)
- Polycyclic aromatic hydrocarbons (PAHs)
- “Emerging Pollutants” such as ammonium and endocrine disrupting chemicals (EDCs)

Contaminant effects are generally species-specific. Pesticides and heavy metals are more likely to directly affect lower trophic levels, with potential negative effects on species composition and food web dynamics. At higher trophic levels, toxic effects are less likely to cause direct mortality, but sublethal toxicity may reduce ecological fitness through impaired growth, reproduction, or behavior, or by increasing the organism’s susceptibility to disease (Werner et al., 2008).Some additional background on specific classes of contaminants as stressors on Delta and Suisun Marsh species and ecosystems is provided below.

Pesticides

As discussed previously, large quantities of pesticides have been and are currently used in the Delta watershed, both for agricultural and urban uses; complex factors affect the rates and timing of inputs of these into estuary waters, including application rates, timing of application, and runoff events (Kuivila and Jennings, 2007; Luoma et al., 2008). Even pesticides that have been banned or restricted from use continue to have persistent toxic effects (Bay Institute, 1998; Smalling et al., 2007; Luoma et al., 2008). Thus, the ecological effects of pesticides include the cumulative influence of pesticides used historically, as well as ongoing inputs of new pesticides (Luoma et al., 2008).

Pesticide concentrations in undiluted agricultural runoff are often acutely toxic to fish and invertebrates (Nobriga, 2008). With dilution in larger Delta waters, acute toxicity from current-use pesticides is much rarer in invertebrates and fishes, but chronic or sublethal contaminant effects are still widespread (e.g., impaired growth, reproduction, or behavior, or increases in susceptibility to disease) (Nobriga, 2008; Werner et al., 2008).

Mercury

Mercury contamination in the Delta and Suisun Marsh primarily resulted from hydraulic gold mining and mercury mining activities in the late 1800s. Methylating bacteria in sediment (particularly sediments in wetlands that have long cycles of wetting and drying such as that found on seasonal floodplains and seasonal wetlands) generate methylmercury from inorganic mercury, making it bioavailable to be taken up into the food web. There are many controls affecting mercury methylation rates, including the amount and type of inorganic mercury available, the distribution and abundance of methylating and de-methylating bacteria, and physical environmental factors in the sediment including availability of oxygen, sulfate, iron, and organic material (Alpers et al., 2008; Luoma et al., 2008; Marvin-DiPasquale and Agee, 2003). Upland wetlands (e.g., seasonal wetlands, diked managed seasonal wetlands, seasonal floodplains, and the highest elevation tidal marsh) that dry out between inundation events often have relatively high levels of methylmercury compared to more consistently inundated wetland types (such as subtidal habitats and tidal marsh) (Alpers et al., 2008). Additionally, some regions have greater methylmercury contamination than others; e.g., the Cache Creek watershed in the northern Delta is considered a mercury hotspot for fish toxicity (Luoma et al, 2008).

Methylmercury is taken up by algae and phytoplankton, and magnified about four-fold in concentration with each increase in trophic level from prey to predator, leading to greatest toxicity for higher predators such as predatory birds and fishes (Alpers et al., 2008; Luoma et al., 2008). Along with increasing with trophic position, mercury also tends to increase in biota with age or size, growth rate, foraging habitat, and foodweb structure; thus, accumulation risks are species and habitat-specific (Alpers et al., 2008, and references therein). Effects of mercury toxicity on wildlife are variable and often species-specific, including neurological, hormonal and behavioral changes, immune system effects, reproductive toxicity, and direct mortality (Alpers et al., 2008); all of these factors can lead to population declines of fish and wildlife. Methylmercury is also a human neurotoxin and human consumption of affected wildlife provides an exposure route. The State of California has issued fish consumptions warnings for the San Francisco Bay and Delta because of mercury exposure risk[4].

Selenium

Selenium is another major contaminant of agricultural runoff, particularly in the San Joaquin Valley where salt and selenium have concentrated in the soils due to continued irrigation and changes in groundwater hydrology (Luoma et al., 2008). Selenium can also enter estuary waters with discharges from refineries and wastewater treatment plants (Werner et al., 2008). Like mercury, selenium accumulates in the food chain and can cause reproductive toxicity for many fish and wildlife. Exotic clams are highly efficient accumulators of selenium, thus species that feed on these clams (such as bottom feeding waterfowl) are particularly susceptible to selenium toxicity; and predators such as Sacramento splittail, salmon, and sturgeon are also particularly susceptible to selenium loading (Werner et al., 2008; Luoma et al., 2008). Selenium loading was responsible for massive bird deformities and fish extirpations at Kesterson National Wildlife Refuge in the San Joaquin Valley in the 1980s (Werner et al., 2008; Presser and Luoma, 2006).

---

[4] http://oehha.ca.gov/fish/general/sfbaydelta.html.

Nitrogen Loadings

There are many sources of nitrogen for the Delta and Suisun Marsh. The dynamics of the overall nitrogen cycle within the Delta and Suisun Marsh are critical as transformations between the various forms of nitrogen determine ammonia and ammonium concentrations. The nitrification of dissolved ammonia was identified as the primary cause of low dissolved oxygen conditions in the Stockton Deep Water Ship Channel in the early 2000s; the majority of this ammonia came from direct wastewater treatment plant discharges and the transformation of organic nitrogen from upstream (Lehman et al., 2004). The other major nitrogen source is fertilizer in runoff from agricultural areas (mainly) and urban areas (e.g., from lawns).

Nitrogen can be found in several forms in the aquatic environment, with each form having different sources and each form having different implications for the Delta and Suisun Marsh ecosystem. Nitrogen as a nutrient (nitrate) fuels plant growth and thus over-enrichment can favor some species over others, changing the relative abundances of species. Nitrogen as ammonia can be toxic to fish and other aquatic organisms, even at very low concentrations (USEPA, 1999). Nitrogen as ammonium can inhibit nitrate uptake by phytoplankton thus limiting primary and secondary productivity; this effect has been the subject of much recent investigation (Foe et al., 2010; Dugdale et al., 2007; Gilbert. in press). Ammonia may contribute to localized toxicity in delta smelt. Werner et al. (2008) found that water samples collected near a wastewater treatment plant effluent discharge reduced the 4-day survival of larval delta smelt in 2006, but did not affect survival even after 7 days in 2007.

Other Water Quality Issues

The suitability of estuarine fish habitat is influenced by a number of dynamic water quality habitat attributes and stationary, structural habitat attributes (Peterson, 2003). Water quality parameters such as salinity, turbidity, temperature, dissolved oxygen concentration, and water and sediment-borne contaminants are locally important dynamic attributes of fish habitat. Several of these parameters have been discussed previously as individual stressors. Here, the stressful effects of turbidity, temperature, and dissolved oxygen on Delta fish species are described briefly.

Turbidity refers to the clarity of water and is influenced by factors such as suspended sediment concentration, and particulate and dissolved organic matter, which in the Delta are influenced by river flows (Kimmerer, 2004), tidal currents, wind events, and bathymetry (Ruhl et al., 2001). Reduced turbidity may reduce foraging efficiency and increase the vulnerability of delta smelt and other fish species to predation. Feyrer et al. (2007) determined that turbidity is a significant predictor of delta smelt occurrence in the Delta; delta smelt occurrence increases with higher turbidity.

Water temperature is an important determinant of fish metabolic and growth rates, so it affects estuarine habitat suitability through a variety of mechanisms (Lankford and Targett, 1994; Marine and Cech, 2004). Delta smelt are sensitive to exposure to elevated water temperatures (Swanson and Cech, 1995) and water temperatures greater than 22 to 25ºC can limit the distribution of delta smelt during the summer (Nobriga et al., 2008). Stress experienced by rearing delta smelt during the warmer summer months, which include the synergistic effects of salinity and seasonally elevated water temperatures, have been hypothesized to be a potentially significant factor affecting delta smelt survival, abundance, and subsequent reproductive success within the Bay-Delta estuary (Bennett, 2005).

High water temperatures can lead to physiological stress and negatively affect salmonid growth rates, smoltification, and ability to escape from predators (Myrick and Cech, 2001; Marine and Cech, 2004). Temperature can also indirectly influence disease incidence and predation. High water temperatures are mainly a concern for salmonids in their upstream (outside the Delta) spawning and rearing grounds. However, high water temperatures in the Delta can negatively affect rearing salmonids and disrupt or delay migration of both spawning adults and emigrating juvenile salmon and steelhead. High water temperature often increases fish sensitivity to low dissolved oxygen concentrations (Cech et al., 1990).

In most of the San Francisco Estuary most of the time, dissolved oxygen is high enough so that it does not impact fish distributions (Kimmerer, 2004). However, there are two known problem areas in the estuary for low dissolved oxygen, both in highly altered habitats. There is a reduction in dissolved oxygen levels during the summer-fall in 14 km of the San Joaquin Deepwater Ship Channel (Lehman et al., 2004), largely due to low flows through this deeply channelized reach (Jassby and Van Nieuwenhuyse, 2006). Some channels in Suisun Marsh also have low dissolved oxygen seasonally due to discharge of low oxygen water from managed wetlands into the adjacent marsh channels (Robert Schroeter, UC Davis unpublished data; cited in Nobriga, 2008). A State Water Resources Control Board study will be completed in late 2010 examining in detail the biogeochemical processes responsible for these events and recommendations for their reduction in the diked managed wetlands of Suisun (Stuart Siegel, Lead Principal Investigator, unpublished data).

Harvest

Harvest occurs primarily in the ocean, but some harvest of adult salmonids migrating upstream through the Delta occurs seasonally. Ocean sport and commercial harvest of fall-run Chinook salmon also results in harvest of spring-run and winter-run Chinook. Both runs are also vulnerable to illegal inland harvest due to long holding periods in freshwater pools. A limited number of Central Valley steelhead are caught during the commercial ocean salmon fishery and the regulated sport fishery. Existing regulations for the steelhead sport fishery have been developed to target hatchery fish. Green sturgeon are captured incidental to other ocean harvest activities and are subject to illegal harvest on their spawning grounds. Sacramento splittail are harvested during their spawning migrations in the spring, although recent regulations were passed to limit harvest by anglers. Other game and non- game fish species are also impacted by fishing activities, both regulated and unregulated.

Hatcheries

Hatchery production has been shown to negatively affect the genetic diversity and fitness of wild salmonid populations. Moderate to high numbers of hatchery fish may impact the genetic diversity of wild populations of Central Valley salmon and steelhead. Hatchery fish compete with wild fish for food, habitat, and mates. Hatchery fish are frequently less productive than wild fish. A very large portion of the existing genetic diversity in Central Valley salmonids is contained in hatchery origin stocks and, in some cases, hatchery stocks may be important contributors to recovery of the species.

The Delta at Ecological Risk: Indicators of Poor Ecosystem Function

The functioning of the Delta and Suisun Marsh ecosystem can be inferred from the following indicators:

- Population declines of native species
- Impaired primary and secondary production
- Low variability in the aquatic environment
- Minimal and uniform habitats and poor connectivity
- Poor transit corridors for migratory fish
- Poor water quality

Each of these indicators is discussed briefly below.

Population Declines of Native Species

Across a broad range of functional groups of native species that utilize the Delta there have been major recent population declines, some of the high profile species are: Delta smelt, salmon, giant garter snake, Swainson's hawk, and greater sandhill crane. Their past declines already lead to their protected status and, with the recent declines, provide clear indication of the Delta's degraded ecological functions

Impaired Primary and Secondary Production

Reduced primary production, a shift in phytoplankton assemblages away from diatoms, and loss of productivity to invasive species have resulted in greatly reduced capacity to support higher trophic level native aquatic organisms.

Low Variability in the Aquatic Environment

Low intra- and inter-annual variability in inflows and outflows, environmental water quality, residence time, and channel geometry have resulted in greatly reduced ability to support the life history requirements of native species that utilize or depend on the Delta at different locations and times of year.

Minimal and Uniform Habitats and Poor Connectivity

Major loss of natural habitats and reduced diversity and connectivity of remaining habitat types has resulted in greatly reduced capacity to meet the life history requirements of native species that utilize or depend on the Delta at different locations and times of year.

Poor Transit Corridors for Migratory Fish

Altered flow regimes, diversions, predators, and poor water quality have adversely affected juvenile and adult migration success leading to declines in abundance and fitness.

Poor Water Quality

Water quality in the Delta has changed greatly over the past 160 years. Runoff from mining, agriculture, urban areas, and industry contributes numerous pollutants to the Delta, in particular metals such as selenium and mercury, pesticides, ammonium and other nutrients, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), endocrine disrupting chemicals (EDCs), oil and grease, and pathogens. These contaminants can have complex direct and indirect adverse effects on wildlife, interfere with ecosystem productivity, alter food web structure, and impact public health.

Section 5
Current Ecosystem Restoration Funding Programs

Funding for ecosystem restoration and enhancement projects in the Delta and areas that influence the Delta comes from a variety of state, federal, local, and private sources. Several of the funding mechanisms with direct bearing on Delta ecosystem restoration are summarized in Table 5-1, below.

Table 5-1
Current Delta Ecosystem Funding Sources

Funding Source	Description
Proposition 84 – Bay-Delta Ecosystem Restoration Program	Under Proposition 84, the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006, bond funds are allocated for use to benefit Bay-Delta associated fish species as part of the Ecosystem Restoration Program (ERP). The ERP was developed as the central plan for restoration and conservation efforts of northern San Francisco Bay, Suisun Marsh, the Sacramento–San Joaquin Delta, and tributaries. The restoration program is an ambitious 30-year effort to restore native fishes and habitats within the CALFED Bay-Delta area. The selection of projects is guided by the ERP Strategic Plan. The Program has an extensive scientific, agency and stakeholder review process to assure the appropriateness for projects selected for funding. Projects are solicited through an open public solicitation process or by directed action by the implementing agencies. Funded projects include the following. • BREACH III: Evaluating and Predicting 'Restoration Thresholds' in Evolving Freshwater-Tidal Marshes • Hill Slough West Restoration Project, Phase I - Preliminary Restoration Design, Environmental Documentation and Permitting • Lower Yolo Bypass Collaborative Process Project • Meridian Farms Water Company Fish Screen Project - Construction Phase 1 • Sacramento Valley/Delta Fish Screen Program • Suisun Marsh Land Acquisition and Tidal Marsh Restoration - Elevation and Contaminant Surveys, Review of Land Acquisition Package, and Review of Property Appraisal • Suisun Marsh Land Acquisition and Tidal Marsh Restoration - Public Notification and Site Selection

Table 5-1
Current Delta Ecosystem Funding Sources

Funding Source	Description
Proposition 84 - Agricultural Grants - Ecosystem Restoration on Agricultural Lands Program	Under Proposition 84, the Wildlife Conservation board (WCB) receives funding for a grant program for “Assist Farmers in Integrating Agricultural Activities with Ecosystem Restoration and Wildlife Protection.” The grant funds are available to public agencies and non-profit conservation groups to assist landowners in implementing conservation-based farming practices that benefit habitat and wildlife. A similar program was developed under the CALFED Bay-Delta, Ecosystem Restoration Program, called Projects that Assist Farmers in Integrating Agricultural Activities with Ecosystem Restoration.
Proposition 1E – Habitat Conservation Fund	Under Proposition 1E, the Disaster Preparedness and Flood Protection Bond Act of 2006, funding is allocated to the Habitat Conservation Fund. Grants and funding distributed under this section can occur through most of the acquisition and restoration programs administered by the WCB, including: • Land Acquisition; • Habitat Enhancement and Restoration; • California Riparian Habitat Conservation; • Inland Wetlands Conservation; • Ecosystem Restoration on Agricultural Lands. These funds are available to support restoration actions in the Delta.
Proposition 1E – Floodway Corridor Program	The Floodway Corridor Program is administered by DWR and includes direct expenditure projects, capital improvement projects, and competitive grants to public agencies and non-profit organizations for flood risk reduction projects. Eligible activities include acquiring rights-of-ways for flood corridors, construction of levees for corridors and bypasses, conservation of agricultural land and wildlife habitat, relocating or flood-proofing structures, and mapping flood hazard areas. Rules for allocation of program funds are developed and vetted through a public process in accordance with the bond statute and applicable legislation. Projects funded under this program may directly or indirectly support restoration of the Delta ecosystem.
Central Valley Project Improvement Act – Central Valley Project Restoration Fund	The CVPIA established the "Central Valley Project Restoration Fund" and gives the Secretary the authority to use this fund "to carry out the habitat restoration, improvement and acquisition (from willing sellers) provisions" of the CVPIA (section 3407). The fund is based in part on Congressional appropriations and on a surcharge imposed on CVP water and power contractors.

Table 5-1
Current Delta Ecosystem Funding Sources

Funding Source	Description
Delta Fish Agreement (Four Pumps Project)	The 1986 Delta Pumping Plant Fish Protection (Delta Fish) Agreement between the Department of Water Resources and the Department of Fish and Game provides a mechanism for offsetting adverse fishery impacts caused by the diversion of water at the Harvey O. Banks Delta Pumping Plant, a part of the State Water Project located at the head of the California Aqueduct. Direct losses of Chinook salmon, steelhead, and striped bass are offset or mitigated through the funding and implementation of fish mitigation projects. DWR and DFG work closely with the Fish Advisory Committee to implement the agreement and projects funded under the agreement. The Fish Advisory Committee is made up of representatives of the State Water Contractors, sport and commercial fishing groups, and environmental groups. The agreement was signed by the Directors of DWR and DFG on December 30, 1986, and has been amended twice since that time. The Delta Fish Agreement is also commonly known as the Four Pumps Agreement because it was subsequently identified as mitigation for the enlargement of the Banks Pumping Plant, including four additional pumps. DWR funds these projects through State Water Project Funds provided by the State Water Contractors in two accounts: (1) a $15 Million Lump Sum Account and (2) an annual Mitigation Account. Mitigation fund expenditures through December 31, 2009 were $40.6 million for the Annual Mitigation Account and $13.3 million for the $15 Million Lump Sum Account. Funds approved but unexpended from each account were $8.0 million and $1.6 million, respectively. The remaining funds are allocated for new or longer-term projects.
Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project National Marine Fisheries Service	On June 4, 2009, NMFS issued a final biological opinion finding that continued operations of the Central Valley Project/State Water Project would likely jeopardize several listed species, including Sacrament River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, Central Valley steelhead, Southern Distinct Population Segment of North American green sturgeon, and Southern Resident killer whales. The biological opinion is effective through December 31, 2030. In its final biological opinion, NMFS identified a Reasonable and Prudent Alternative (RPA) that, if implemented, is believed to avoid the likelihood of jeopardizing the continued existence of these listed species. CVP and SWP would fund these actions as a condition of the Biological Opinion.
Biological Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (Delta smelt)	On December 15, 2008, the U.S. Fish and Wildlife Service (USFWS) delivered its Biological Opinion to the U.S. Bureau of Reclamation on the effects of the continued operation of the federal Central Valley Project and the California State Water Project on the delta smelt and its designated critical habitat. USFWS determined that the continued operation of these two water projects is likely to jeopardize the continued existence of the delta smelt and adversely modify its critical habitat. USFWS identified Reasonable and Prudent Alternatives intended to protect each life-stage and critical habitat of this federally protected species. Implementation of the RPAs would be funded by the CVP and SWP as a condition of the Biological Opinion.

Section 6
Jurisdictional Responsibilities

Because of the current state of the Delta ecosystem, there are numerous regulations, policies, programs, and plans currently in place that are intended to improve the condition of the ecosystem or stem the decline of individual species, and additional processes (e.g., development of Habitat Conservation Plans [HCPs]) are under way. For the most part, these efforts are in response to specific actions intended to mitigate or avoid the impacts of activities that could adversely affect the Delta ecosystem or the imperiled species it supports. Collectively, these efforts contribute to improving the Delta ecosystem, but they are generally not well coordinated and responsibility for their implementation is broadly held by numerous entities.

This collection of regulations, policies, programs, and plans contribute to the setting within which the Council will develop the ecosystem elements of the Delta Plan, and they may constrain or influence future decisions. The following provides a brief overview of existing conservation plans, biological opinions, and policies that have wide-reaching influence on ecosystem management in the Delta.

Conservation Plans

The federal Endangered Species Act and California Endangered Species Act generally prohibit the take (e.g., killing, capturing, and harming) of listed species without specific authorization. Under Section 10 of the federal act, an individual or non-federal entity can apply for a permit that allows for the limited take of a listed species that is incidental to an otherwise lawful activity. The issuance of the incidental take permit requires the development of an HCP that shows how the applicant will minimize and mitigate the take to the maximum extent practicable. These plans typically address large-scale changes in the environment (e.g., urban development) over timeframes of 30 years or more, and spell out where and how mitigation will be conducted.

A similar, but more broadly based, planning and permitting process is afforded by the state Natural Community Conservation Planning Act, which takes an ecosystem approach to planning for the protection and perpetuation of biological diversity. A Natural Community Conservation Plan (NCCP) identifies and provides for the regional protection of plants, animals, and their habitats. Although an NCCP supports the issuance of incidental take permits for state-listed species, the primary objective of the NCCP program is to conserve natural communities at the ecosystem level while accommodating compatible land use. The program, administered by DFG, seeks to anticipate and prevent the controversies and gridlock caused by species' listings by focusing on the long-term conservation (recovery) of wildlife and plant communities and including key interests in the process.

Development of HCPs and NCCPs requires a substantial investment and a long-term commitment to funding conservation and mitigation measures in accordance with the plan. In exchange, the permittees gain comprehensive regulatory coverage for currently listed species and those that may be in the future, and regulatory assurances that guarantee landowners and others predictability, reliability, and certainty regarding endangered species regulation now and in the future. It also provides predictability, streamlining, and efficiency to state and federal regulatory programs that protect endangered species. Major amendments to these plans require additional scientific information supporting the amendment and all parties signatory to the plan must approve of the amendment in writing.

Broad-scale conservation plans are already in place in San Joaquin County and a portion of east Contra Costa County, including small areas within the Delta (Figure 6-1). Conservation planning efforts are currently under way to address future land use changes in Yolo, Solano, and south Sacramento counties. The Bay Delta Conservation Plan, also an HCP/NCCP, is intended to support the issuance of incidental take permits for the operation of the state and federal water system (see Figure 6-1). These are briefly described below in Table 6-1.

Figure 6-1
Conservation Plans in the Delta Region
Source: DFG 2009

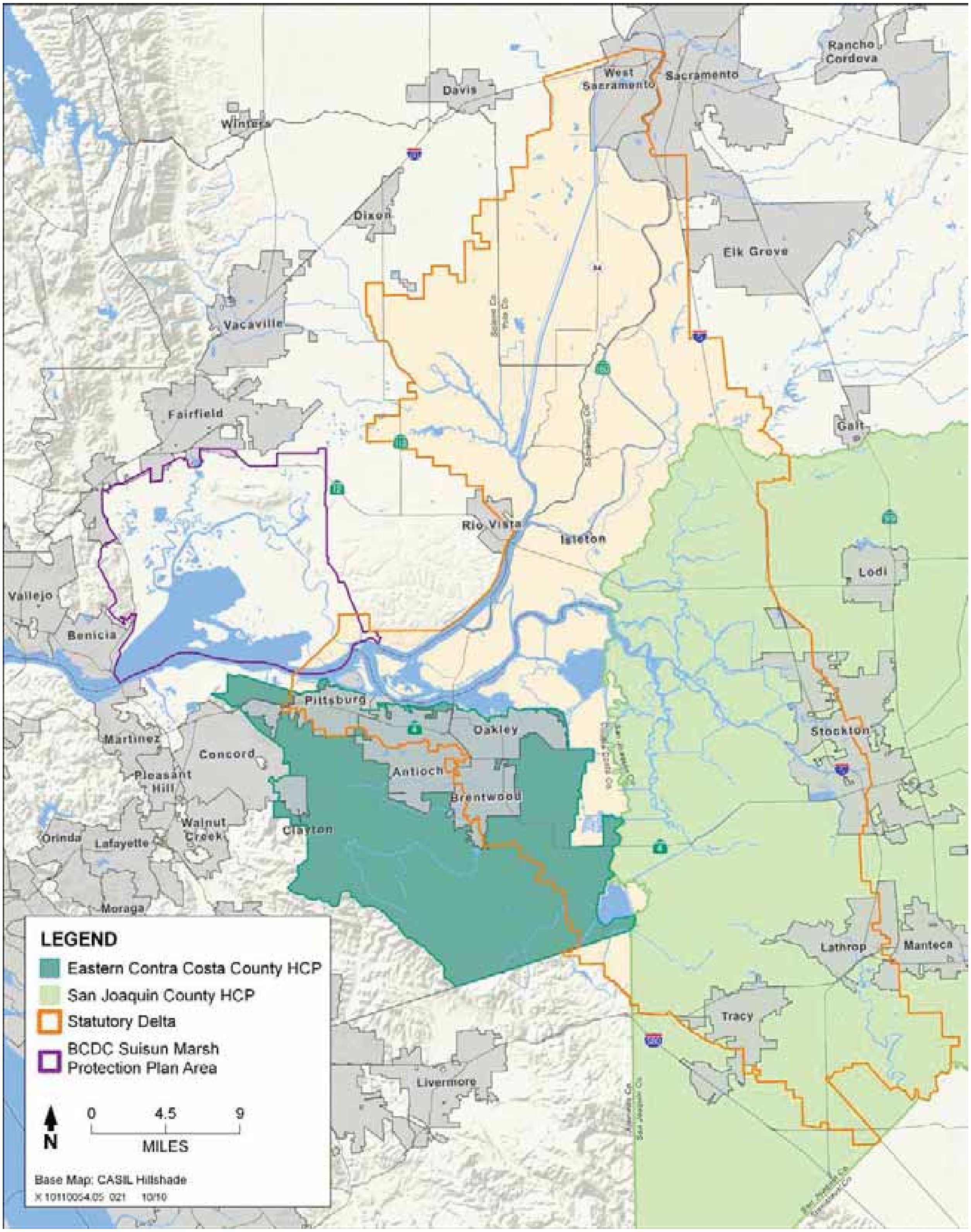


Table 6-1
Existing Conservation Plans Affecting the Delta Ecosystem and Plans under Development

Plan/Agencies	Description
San Joaquin County Multi-Species Habitat Conservation and Open Space Plan San Joaquin Council of Governments	The San Joaquin County Multi-Species Habitat Conservation and Open Space Plan (Plan), which covers most of the nonfederal lands in the county, was completed in 2000. The purpose of the Plan is to provide a strategy for balancing the need to conserve open space and the need to convert open space to non-open space uses. These goals are intended to be met while protecting the region's agricultural economy; preserving landowner property rights; providing for the long-term management of plant, fish and wildlife species, especially those that are currently listed, or may be listed in the future, under the federal Endangered Species Act or the California Endangered Species Act; providing and maintaining multiple-use open spaces that contribute to the quality of life of the residents of San Joaquin County; and accommodating a growing population while minimizing costs to project proponents and society at large. The Plan addresses the past and future growth that affects 97 special status plant, fish and wildlife species in 52 vegetative communities scattered throughout San Joaquin County, which includes 43% of the Sacramento-San Joaquin Delta's Primary Zone. The Plan provides compensation for the conversion of open space to non-open space uses which affect the plant, fish and wildlife species covered by the Plan. The conservation strategy relies on minimizing, avoiding, and mitigating impacts on the species covered by the Plan. When impacts are unavoidable, impacts on covered species are addressed through a habitat-based approach that emphasizes compensation for habitat losses through the establishment, enhancement and management-in-perpetuity of preserves composed of a specific vegetation types or association of vegetation types upon which covered species rely. The purchase of easements from landowners willing to sell urban development rights is the primary method for acquiring preserves. The Plan identifies zones distinguished by a discrete association of soil types, water regimes (e.g., Delta lands subject to tidal influence, irrigated lands, lands receiving only natural rainfall), elevation, topography and vegetation types. In general, impacts within a particular zone are mitigated within the same zone.
East Contra Costa County Habitat Conservation Plan/Natural Community Conservation Plan Contra Costa County and East Contra Costa County Habitat Conservancy	The East Contra Costa County Habitat Conservation Plan/Natural Community Conservation Plan (Plan) was adopted in 2006 and provides regional conservation and development guidelines to protect natural resources while improving and streamlining the permit process for endangered species and wetland regulations. Within the 174,018- acre inventory area, the Plan provides permits for between 8,670 and 11,853 acres of development and will permit impacts on an additional 1,126 acres from rural infrastructure projects. The Plan will result in the acquisition of a preserve system that will encompass 23,800 to 30,300 acres of land that will be managed for the benefit of 28 species as well as the natural communities that they depend upon. The East Contra Costa County Habitat Conservancy is a joint exercise of powers authority formed by Contra Costa County and the cities of Brentwood, Clayton, Oakley and Pittsburg to implement the Plan. It allows Contra Costa County, the Contra Costa County Flood Control and Water Conservation District, the East Bay Regional Park District and the cities of Brentwood, Clayton, Oakley, and Pittsburg (collectively, the Permittees) to control permitting for activities and projects they perform or approve in the region that have the potential to adversely affect state- and federally listed species. The Plan also provides for comprehensive species, wetlands, and ecosystem conservation and contributes to the recovery of endangered species in northern California. The HCP/NCCP inventory area includes two small areas within the Primary Delta Zone, including land between Clifton Court Forebay and the Contra Costa County line, and a portion of the agricultural area northeast of the Brentwood city limit and south of the Oakley city limits. Actions in these areas are consistent with the direction provided by the Delta Protection Commission.

Table 6-1
Existing Conservation Plans Affecting the Delta Ecosystem and Plans under Development

Plan/Agencies	Description
Solano Multispecies Habitat Conservation Plan Solano County Water Agency	The Solano Habitat Conservation Plan (HCP) is intended to support the issuance of an incidental take permit under the federal Endangered Species Act for a period of 30 years. This permit is required by the March 19, 1999 Solano Project Contract Renewal Biological Opinion between the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation. The scope of the Solano HCP was expanded beyond the requirements of the Biological Opinion to include additional voluntary applicants and additional species for incidental take coverage. These additional species include federally listed fish species under the jurisdiction of the National Marine Fisheries Service and species listed as threatened or endangered under the California Endangered Species Act. The HCP further addresses other species of concern (i.e., species recognized by groups such as the California Department of Fish and Game and California Native Plant Society as having declining or vulnerable populations, but not officially listed as threatened or endangered species). Thirty-seven (37) species are proposed to be covered under the Solano HCP. The minimum geographical area to be covered is the Solano County Water Agency's contract service area that is the cities of Fairfield, Vacaville, Vallejo, Suisun City, the Solano Irrigation District and the Maine Prairie Water District. The area covered by the HCP is all of Solano County and a small portion of Yolo County. The HCP will include a Coastal Marsh Natural Community Conservation Strategy designed to maintain the water and sediment quality standards, hydrology and ecological functions of this natural community; contribute to the restoration of tidally influenced coastal marsh habitat; contribute to the conservation and recovery of associated covered species; and promote habitat connectivity. Primary conservation actions include preservation (primarily through avoidance), restoration, invasive species control, and improvement of water quality. The plan will cover 580,000 acres, including 12,000 acres of proposed development and 30,000 acres that will be preserved.
Yolo County Habitat/Natural Community Conservation Plan Yolo County Habitat Joint Powers Authority	The Yolo County Habitat Joint Powers Authority (JPA), comprised of five local public agencies and the University of California at Davis, launched the Yolo Natural Heritage Program in March 2007. This effort includes the continuing preparation of a joint Habitat Conservation Plan/ Natural Community Conservation Plan (HCP/NCCP). Member agencies include: Yolo County, City of Davis, City of Woodland, City of West Sacramento, City of Winters, and the University of California, Davis as an ex-officio member. The HCP/NCCP will describe the measures that local agencies will implement in order to conserve biological resources, obtain permits for urban growth and public infrastructure projects, and continue to maintain the agricultural heritage and productivity of the county. The nearly 653,820-acre planning area provides habitat for 65 listed and at risk species occurring within five dominant habitats/natural communities. The JPA expects to approve the HCP/NCCP in 2011. Interim conservation activities include acquiring permanent conservation easements for sensitive species habitat in the plan area.
Bay Delta Conservation Plan	The Bay Delta Conservation Plan is an HCP and NCCP under federal and state laws that will address the take of covered species resulting from the continued operation of the state and federal water projects and provide the basis for the issuance of incidental take permits through USFWS, NMFS, and DFG. The plan considers a 50-year planning period, and focuses on a long-term conservation strategy that sets forth actions needed support a healthy Delta ecosystem.

Biological Opinions

Section 7 of the federal Endangered Species Act, requires all federal agencies to consult with the National Marine Fisheries Service (NMFS) for marine and anadromous species, or the United States Fish and Wildlife Service (USFWS) for freshwater and wildlife species, if they are proposing to authorize, fund, or carry out an action that may affect listed species or their designated critical habitat. Typically, the federal agency taking the action prepares a biological assessment to determine whether the proposed action is likely to adversely affect listed species or designated critical habitat. Through evaluation of the biological assessment and other information, NMFS and/or USFWS will determine whether or not the federal action is likely to jeopardize the continued existence of listed species, or result in the destruction or adverse modification of designated critical habitat. If jeopardy or adverse modification is found, the biological opinion will suggest reasonable and prudent alternatives that the agency or applicant could take to avoid jeopardy or adverse modification. If the agency or applicant agrees with these, NMFS and/or USFWS will issue an incidental take statement. However, if the aagency or applicant cannot agree, they risk violating the ESA if they proceed with the project as proposed.

The long-term operations of the Central Valley Project and State Water Project were recently reviewed by NMFS and USFWS and their findings were published in two separate biological opinions. In both documents, continued long-term water operations were determined to jeopardize the continued existence of listed species. The biological opinions contained reasonable and prudent alternatives, which are summarized in Table 6-2.

Table 6-2
Current Biological Opinions Affecting the Delta Ecosystem

Plan/Agencies	Description
Biological Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (Delta smelt)	On December 15, 2008, the U.S. Fish and Wildlife Service (USFWS) delivered its Biological Opinion to the U.S. Bureau of Reclamation on the effects of the continued operation of the federal Central Valley Project and the California State Water Project on the delta smelt and its designated critical habitat. USFWS determined that the continued operation of these two water projects is likely to jeopardize the continued existence of the delta smelt and adversely modify its critical habitat. USFWS identified Reasonable and Prudent Alternatives (RPAs) intended to protect each life-stage and critical habitat of this federally protected species. The RPAs include the following actions: 1) prevent/reduce entrainment of delta smelt at Jones and Banks; 2) provide adequate habitat conditions that will allow the adult delta smelt to successfully migrate and spawn in the Bay-Delta; 3) provide adequate habitat conditions that will allow larvae and juvenile delta smelt to rear; and 4) provide suitable habitat conditions that will allow successful recruitment of juvenile delta smelt to adulthood.

Table 6-2
Current Biological Opinions Affecting the Delta Ecosystem

Plan/Agencies	Description
Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project	On June 4, 2009, NMFS issued a final biological opinion finding that continued operations of the Central Valley Project/State Water Project would likely jeopardize several listed species, including Sacrament River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, Central Valley steelhead, Southern Distinct Population Segment of North American green sturgeon, and Southern Resident killer whales. The biological opinion is effective through December 31, 2030. In its final biological opinion, NMFS identified a Reasonable and Prudent Alternative (RPA) that, if implemented, is believed to avoid the likelihood of jeopardizing the continued existence of these listed species. The following summarizes the actions identified in the RPA that would be undertaken by the U.S. Bureau of Reclamation and/or the California Department of Water Resources. Although many of these actions take place outside the Delta, they benefit species that use the Delta. • Manage water temperature and water storage in Shasta Reservoir to benefit winter-run Chinook salmon in the Sacramento River • Provide flows and adequate water temperatures in Clear Creek to benefit spring-run Chinook salmon • Modify gate operation of the Red Bluff Diversion Dam (with the objective of removing the gates by 2012) to improve passage for salmon and green sturgeon • Improve juvenile salmonids rearing habitat in the lower Sacramento River and northern Delta • Improve survival of migrating juveniles by implementing additional gate closures at the Delta Cross Channel • Limit the strength of reverse flows in Old and Middle rivers to reduce entrainment of juvenile fish into the state and federal export facilities in the south Delta • Implement facility improvements at the state and federal export facilities to increase fish survival • Increase San Joaquin River flows, curtail exports, and implement a fish study using acoustic tags, to improve the ability to increase survival of juvenile steelhead migrating from the San Joaquin River basin • Implement a flow management standard, temperature management plan, and facility modifications to improve conditions for steelhead in the American River • Implement a new year-round minimum flow regime that improves conditions for steelhead in the Stanislaus River • Develop a Hatchery Genetic Management Plans to increase and stabilize the prey base for Southern Resident killer whales • Provide long-term fish passage at Keswick and Shasta dams on the Sacramento River, Nimbus and Folsom dams on the American River, and New Melones Dam on the Stanislaus River The final biological opinion also identified research, monitoring, and reporting requirements.

U.S. Army Corps of Engineers Levee Vegetation Policy

Many of the built levees of the Sacramento and San Joaquin rivers and other waterways in the Delta and Suisun Marsh support riparian trees and shrubs depending on the levee substrate, this vegetation may range from a single row of trees to well developed multi-storied stands of riparian vegetation. This vegetation may provide a component of SRA cover and provide important habitat for native fish species. However, the land-water interface of flood control levees is much more abrupt than on natural levees, because the slopes of flood control levees are relatively steep (e.g., typically 3:1). Vegetation on flood control levees is frequently removed to allow levee inspections or because it is considered detrimental to the levee stability.

In the wake of Hurricane Katrina in 2005, the U.S. Army Corps of Engineers (USACE) published a white paper (USACE, 2007) and a subsequent Engineering Technical Letter (USACE, 2009) defining as USACE policy that all vegetation with the exception of grasses should be removed from levees and from an additional zone of 15 feet from each side of the toe of the levee. Beyond 15 feet of the water-side toe of a levee the use of suitable vegetation, such as shrubby willows, is encouraged to moderate the erosive potential of water currents. The local sponsor of flood control projects may in certain instances, request a variance from the standard vegetation guidelines to further enhance environmental values or to meet state or federal laws and/or regulations (75 FR 6364-6368, February 9, 2010).

The USACE has also indicated that it supports the Central Valley Floodsystem Improvement Framework Agreement that was adopted by the Central Valley Flood Protection Board which includes many ongoing flood control system improvements, and which will remain in effect until July 2012, when the Central Valley Flood Protection Plan will be completed (Stockton, pers. comm.). With its support of the Central Valley Framework Agreement, “which recognizes that factors, other than vegetation on levees, may constitute higher flood risk” (Stockton, pers. comm.), the USACE has given California in practice a reprieve from its “no vegetation on levees” policy until July 2012. Currently, a group of researchers funded by the Sacramento Area Flood Control Agency and a separate group of USACE researchers are conducting field studies on the effects of vegetation on levee stability, and the results of these studies may be used by USACE to provide future guidance.

Section 7
Future Issues Affecting the Delta Ecosystem

As described above, the health of the Delta ecosystem is currently challenged by a variety of factors that diminish its ability to function and provide services that benefit the species it supports and humans. Moving forward, many of the same factors that currently drive ecosystem health and stress Delta species will continue to exert pressure on the system. This section briefly summarizes some of the factors that could present significant issues related to restoration of the Delta ecosystem in the future.

Diversions, Exports, and Conveyance

Diversions upstream of (e.g. in the Sacramento River) and within the Delta, conveyance across the Delta, water exports from the Delta, and maintaining export water quality have significant effects on the Delta ecosystem and have the potential to continue to put components of the ecosystem at risk. Diversions entrain fish and their food resources and increase the risk of predation by trapping fish in diversion forebays. Flow direction and magnitudes affect migration and movement of fish and their food supplies, limit access to suitable habitats, and alter water quality. Water supply management affects salinity and residence time which, in turn, affects many related ecological processes such as primary and secondary production. Constructed waterways for conveyance have created artificial links among natural waterways, altering flow direction and volume, salinity and residence time. Diversions, exports, and conveyance of water from and within the Delta will be controlled in the future by a number of entities as governed by a variety of plans, policies, agreements, and permits (see Section 6, “Jurisdictional Responsibilities”).

Population Growth and Private Lands

The Delta is surrounded by some of the most rapidly urbanizing areas in California. Excluding land already developed or land set aside for conservation, approximately 160,000 acres of additional land within the Delta-Suisun could be urbanized. Depending on the density of the development, this could increase Delta-Suisun population over 2000 population by 600,000 to 900,000 people. This estimate is in line with Department of Finance data that project a Delta-Suisun population increase of about 600,000 people by 2050 (DWR, 2007).

Urbanization has resulted in increased runoff to Delta waterways, and has increased infrastructure in the Delta that serves urban areas outside the Delta. Population growth in other areas of California is increasing demand for irrigation and drinking water supplies from the Delta. In addition, development on the periphery of the Delta removes lands that are suitable for restoration and important to accommodate sea level rise, exacerbates the many stressors that accompany urbanization, forces levee maintenance, and complicates nearby restoration efforts by creating and increasing the need for flood control. This rapidly growing demand for Delta resources may not be sustainable at current levels, and it will likely become increasingly difficult to balance the coequal goals as they relate to the Delta ecosystem.

Climate Change – Sea Level Rise, Climate Variability, and Storm Frequency and Intensity

Global climate change is expected to increase sea levels and temperatures and affect local weather patterns. As sea level rises, intrusion of brackish water into the Delta is expected to increase; this intrusion of sea water would raise water surface elevations in the Delta, increasing the differential between water surface elevation in channels and land elevations on Delta islands.

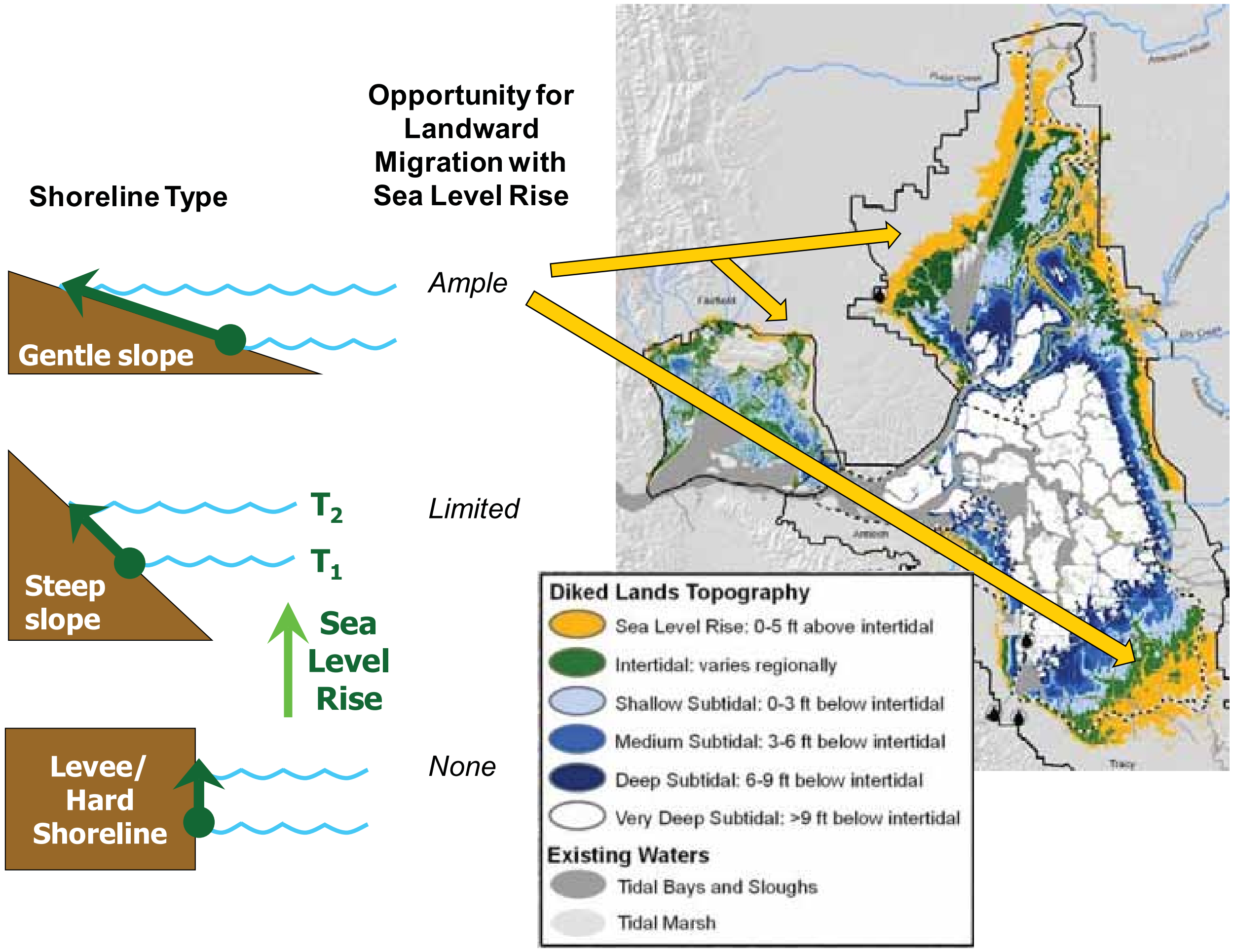
The land-water interface is predicted to move to higher elevations as a result of climate change induced sea level rise. The mean tide level is expected to move 12 to 18 inches above the current level by 2050 and 21 to 55 inches by 2100, increasing at an accelerating rate (California Resources Agency, 2009). In addition to sea level rise, climate change is also expected to increase the frequency, duration and height of flood flows, because of continued shifts in California precipitation away from snowfall to rain (California Resources Agency, 2009). This will further exacerbate, in winter, the impact of sea level rise on tidal marshes and riparian forest and scrub. In addition, precipitation models suggest a trend toward reduced precipitation in the future (California Resources Agency, 2009), which could influence the amount of water entering the Delta.

Effects of sea level rise on tidal marsh and riparian vegetation depend on the potential for sediment and organic accretion (material buildup), and on the opportunity for the marsh to expand land-ward, while the shoreline erodes (Orr et al., 2003). Substrate accretion in freshwater tidal marshes is expected to be able to keep pace with at least moderate levels of sea level rise due to organic accretion, but brackish and salt marshes are more dependent on sediment supply for accretion to keep pace with sea level rise (Orr et al., 2003; Callaway et al., 2007). Overall, a loss of tidal marshes is expected, because in many cases an opportunity for landward migration of the marsh does not exist (Figure 7-1).

Global climate change also influences local climate conditions, particularly temperature and precipitation patterns, with implications for future inflows from tributaries to the Delta. With a warmer climate, atmospheric moisture will increase, resulting in more intense and warmer storms. This is expected to increase the size of winter floods (or their frequency) because of more precipitation in each storm and more moisture falling as rain rather than snow. Cumulatively, these changes are expected to put additional pressure on the Delta's fragile levees and increase the intrusion of brackish water into the Delta, with corresponding declines in both habitat and water quality.

In addition, modeling scenarios predict an increase in California's air temperatures in the range of 2-6° C in California (California Climate Change Center, 2006). Because Delta water temperature is determined primarily by air temperature, an increase in water temperatures could exacerbate already poor conditions for native aquatic species that are particularly sensitive to water temperatures. Regional climate change also has the potential to increase the suitability of the Delta to invasions of new species and pathogens (e.g. West Nile virus).

Figure 7-1
Opportunity for Sea Level Rise Accommodation through Estuarine Transgression (Landward Tidal Marsh Migration) as a Function of Upland Slope
Source: Wetlands and Water Resources



New Species Invasions

Introduced species are currently affecting the Delta ecosystem through their past and present effects on native species and their habitats. More introductions of species must be anticipated, in spite of best efforts to prevent them. Species known to be problems in other regions, such as northern pike, zebra mussel, quagga mussel, and various aquarium plants, are likely to invade the Delta and Suisun Marsh. While not yet present in the Delta, these and other species have the potential to become established in the future and could have adverse effects on native species and their habitats.

Levee Integrity (Seismicity, Maintenance, and Hydrostatic Pressure)

The Delta and Suisun Marsh lie near six major faults that are capable of generating moderate to strong ground shaking, particularly in the western Delta. The U.S. Geological Survey estimates a roughly 2-in-3 probability that the Bay Area will experience a large magnitude quake most likely along one of these faults within the next 26 years (DWR, 2007). Although levees in Suisun Marsh are not as high as those in the Delta, they are much closer to several fault lines. In the event of a large earthquake, multiple levee failures and subsequent island inundation are anticipated. Flooding of subsided islands in the western and central delta could increase intrusion of brackish water into the Delta. This would result in short-term and perhaps long-term effects on the Delta ecosystem as well as changes in land use activities, infrastructure, and water supply reliability.

The combination of future subsidence, sea level rise, more winter runoff, and seismic activity make the Delta-Suisun levees more vulnerable to failure. High-water conditions are expected to cause about 140 levee failures within the next 100 years (URS/JBA, 2008b). A major earthquake would have the potential to cause the most catastrophic levee failures and could flood multiple islands. For example, the Delta Risk Management Strategy (DRMS) analysis predicted that there is an approximately 50 percent probability of a major earthquake causing 20 or more islands to flood at the same time in the 25-year period from 2005 to 2030 (URS/JBA, 2008b). Such an event could lead to saltwater intrusion and disruption of water exports for a substantial period of time.

Subsidence

Reclamation of marshes and wetlands in the historical Delta for agriculture has resulted in substantial subsidence of some islands, such that elevations of land in the central and western Delta are well below sea level. Subsidence of Delta islands is expected to continue as long as non-flooded agriculture remains the primary land use on areas with peat soil. Investigations for DRMS estimate as much as 9 feet of additional subsidence in portions of the central Delta by 2100. Over the next 200 years, some areas could subside by another 18 feet from existing land levels if current land use practices continue (DWR, 2007). Continued subsidence will increase the differential between water surface elevation in channels and land elevation and reduce the stability of levees protecting the islands. Subsidence of delta lands has greatly limited the opportunities for restoration because the quality of open water habitat on deeply subsided islands is expected to be low for native species.

Flooded Delta Islands

Approximately 150 years ago, most Delta “islands” were continuous tracts of tidal marsh before they were surrounded by levees. Water levels were higher during winter storms than in the summer, but tidal water-level fluctuations were generally greater than seasonal water-level changes. After levees were built around the islands and they became cultivated for agriculture, a process of land subsidence started, mostly as the result of oxidation of peat soils, but also as the result of wind. Some locations in the Delta are more than 20 feet below sea level (see Figure 4-5). Subsidence has made levees more vulnerable to failure.

Recently, the DRMS investigations conducted for DWR, DFG, and USACE assessed the risks of levee failures in the Delta and Suisun Marsh, including the risk to the ecosystem (URS/JBA, 2008a; 2008b).

Effects of levee failure and flooding of islands on native fish species are complex. Aquatic species could be negatively affected by stranding and elevated levels of suspended sediment on the flooded islands. New habitat created on the flooded islands could benefit aquatic species (at least temporarily). It is unclear whether native species or nonnative species would receive the greatest benefit. For example, Franks Tract, a flooded island in the central Delta, provides habitat to the invasive Brazilian waterweed, which provides cover for introduced predatory fishes, such as largemouth bass (Grimaldo et al., 2004; Nobriga, 2008; Kimmerer et al., 2008).

The degree of impact on terrestrial communities and species depends on the type of vegetation flooded. The DRMS analysis indicated that an event where multiple islands are flooded would result in potential losses of up to 39 percent of herbaceous wetland, seasonal grasses, and “low-lying vegetation”; 29

percent of nonnative trees; and 24 percent of riparian scrub in these areas (URS/JBA, 2008a). These losses would have substantial negative effects on the wildlife species that use these habitats. The failure of levees in Suisun Marsh could result in impacts on several terrestrial wildlife species of concern, including salt marsh harvest mouse and California clapper rail. The DRMS analysis suggests that large-scale levee failures would cause substantial losses of available habitat, food shortages for some species, and displacement of birds and other species.

SWRCB and DFG Flow Recommendations

Water Code section 85086 requires the State Water Resources Control Board to develop, within 9 months of enactment of the requirement, new flow criteria to protect public trust resources for the Delta ecosystem. The statute further requires the State Water Board to submit its flow criteria determinations to the Delta Stewardship Council within 30 days of their development. In accordance with Water Code section 85086, the State Water Board conducted a public process in the form of an informational proceeding, held on March 22-24, 2010, to develop the flow criteria. The State Water Board released a draft Report on Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem on July 21, 2010, for public review and comment. On August 3, 2010, the State Water Board adopted Resolution 2010-0039 approving the final report determining new flow criteria for the Delta ecosystem necessary to protect public trust resources. On August 25, 2010 the Executive Director of the State Water Board submitted the final report to the Delta Stewardship Council.

The Delta Reform Act also requires that DFG, in consultation with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service and based on the best available science, develop and recommend to the board Delta flow criteria and quantifiable biological objectives for aquatic and terrestrial species of concern dependent on the Delta. The recommendations shall be developed no later than 12 months after the date of enactment of this division (November 2010). In September 2010, DFG released its draft report, *Quantifiable Biological Objectives and Flow Criteria for Aquatic and Terrestrial Species of Concern Dependent on the Delta*.

Section 8
References

Alpers, C., C. Eagles-Smith, C. Foe, S. Klasing, M. C. Marvin-DiPasquale, D. G. Slotton, and L. Windham-Myers. 2008. Mercury Conceptual Model, Delta Regional Ecosystem Restoration Implementation Plan.

Atwater, B. F. 1980. Distribution of Vascular-Plant Species in Six Remnants of Intertidal Wetland of the Sacramento-San Joaquin Delta, California. U.S. Geological Survey Open-File Report 80-883.

Atwater, B. F. 1982. Geologic Maps of the Sacramento-San Joaquin Delta, California. U.S. Geological Survey MF-1401, Menlo Park, CA.

Atwater, B. F. and D. F. Belknap. 1980. Tidal-wetland deposits of the Sacramento-San Joaquin Delta, California. In: M. E. Field, A. H. Bouma, I. P. Colburn, R. G. Douglas, and J. C. Ingle (eds.). Quaternary Depositional Environments of the Pacific Coast: Pacific Coast Paleogeography Symposium 4. Proceedings of the Society of Economic Paleontologists and Mineralogists. Los Angeles, CA.

Atwater, B. F., S. C. Conard, I. N. Dowden, C. W. Hedel, R. L. MacDonald, and W. Savage. 1979. History, landforms, and vegetation of the estuary's tidal marshes. Pages 347-385 in: T.J. Conomos, ed. San Francisco Bay: The Urbanized Estuary. Proceedings of the 58th Annual Meeting of the Pacific Division of the American Association for the Advancement of Science, Golden Gate Park, San Francisco, CA.

Babcock, K. W. 1995. Home Range and Habitat Use of Breeding Swainson's Hawks in the Sacramento Valley of California. *Journal of Raptor Research* Volume 29: 193–197.

Baxter, R., R. Breuer, L. Brown, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer, and K. Souza. 2008. Pelagic organism decline progress report: 2007 synthesis of results. Interagency Ecological Program for the San Francisco Estuary. January 2008.

Bay Institute. 1998. From the Sierra to the Sea. The Ecological History of the San Francisco Bay-Delta Watershed. The Bay Institute of San Francisco. San Francisco, CA.

Bennett WA, Moyle PB. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin estuary. In: Hollibaugh JT, editor. San Francisco Bay: the ecosystem. San Francisco (CA): Pacific Division of the American Association for the Advancement of Science. p 519-541.

Bennett, J., J. Hofius, C. Johnson, T. Maurer. 2001. Tissue residues and hazards of water-borne pesticides for federally listed and candidate fishes of the Sacramento-San Joaquin River Delta, California: 1993-1995. U.S. Fish and Wildlife Service. Environmental Contaminants Division. Sacramento, CA. July 2001

Bennett, W. A., W. J. Kimmerer, and J. R. Burau. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low salinity zone. Limnology and Oceanography 47: 1496–1507.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science [online serial]. Vol. 3, Issue 2 (September 2005), Article 1.

Bennett, W.A. 2007. Environmental issues. CALFED Science Workshop: Science Related to an Isolated Facility. 8/22/2007.

Bennett, W.A., W.J. Kimmerer, J.R. Burau. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography. 47:1496-1507.

Brown, Larry R. and Marissa L. Bauer. 2009. Effects of hydrologic infrastructure on flow regimes of California's Central Valley rivers: Implications for fish populations. River Research and Applications, online edition. Abstract access: http://www3.interscience.wiley.com/journal/122508164/abstract?CRETRY=1&SRETRY=0

Brown R, Kimmerer W. 2002. Delta smelt and CALFED's environmental water account: a summary of the 2002 delta smelt workshop. Available at: http://science.calwater.ca.gov/pdf/ewa/EWA_workshop_smelt_summary_100102.pdf

Brown, L.R., D. Michniuk. 2007. Littoral fish assemblages of the alien-dominated Sacramento-San Joaquin Delta, California, 1980-1983 and 2001-2003. Estuaries and Coasts. 30: 186-200.

Brown, Larry R. 2003a. Potential Effects of Organic Carbon Production on Ecosystems and Drinking Water Quality. San Francisco Estuary and Watershed Science 1(1): Article 2. http://escholarship.ucop.edu/uc/item/8xc987c9. Accessed on September 29, 2010.

Brown, Larry R. 2003b. Will Tidal Wetland Restoration Enhance Populations of Native Fishes? San Francisco Estuary and Watershed Science 1(1): Article 3. http://escholarship.ucop.edu/uc/item/2cp4d8wk. Accessed on October 1, 2010.

Bryant, E. 1846. What I Saw in California: Being the Journal of a Tour, in the Years 1846, 1847. Ross and Haines, Inc., Minneapolis, MN. 1967.

CALFED (CALFED Bay-Delta Program). 2000. Ecosystem Restoration Program Plan, Volume I: Ecological Attributes of the San Francisco Bay-Delta Watershed. Final Programmatic EIS/EIR Technical Appendix, July, 2000. 532 pp.

California Department of Water Resources (DWR). 2007. Status and Trends of Delta Suisun Services. Public Review draft. March 2007. Prepared by URS Corporation.

California Natural Resources Agency. 2009. 2009 Climate Change Adaptation Strategy. A Report to the Governor of the State of California in Response to Executive Order S-13-2008. http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF. Accessed on September 30, 2010.

Callaway, J. C., V. T. Parker, M. C. Vasey, and L. M. Schile. 2007. Emerging issues for the restoration of tidal marsh ecosystems in the context of predicted climate change. Madroño 54: 234-248.

CCPW (California Commissioner of Public Works). 1895. Report to the Governor of California, 1983-1894. *In* Appendix to Journal of Senate and Assembly of the 31st Session of the Legislature, Sacramento, CA.

CCWD (Contra Costa Water District). 2010. Historical Fresh Water and Salinity Conditions in the Western Sacramento-San Joaquin Delta and Suisun Bay. Technical Memorandum WR10-001. Water Resources Department, Concord, California. 136 pp.

CDPW (California Department of Public Works). 1931. Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay. Bulletin 27.

Cech, JJ, Jr, Mitchell, SJ, Castleberry, DT, McEnroe, M. 1990. Distribution of California stream fishes: influence of environmental temperature and hypoxia. Environmental Biology of Fishes 29:95-105.

Center for Biological Diversity, The Bay Institute, Natural Resources Defense Council. 2006. Emergency petition to list the delta smelt (Hypomesus transpacificus) as an endangered species under the endangered species Act. Submitted to the U.S. Fish and Wildlife Service, Washington DC and Sacramento Field Office, CA. March 8, 2006. Available at: http://www.biologicaldiversity.org/swcbd/species/deltasmelt/DS-Endangered-Petition-3-8-06.pdf.

CNDDB (California Natural Diversity Database). 2010. Records search of plan area quadrangles. California Department of Fish and Game, Sacramento, California.

CNPS (California Native Plant Society). 2010. Inventory of Rare and Endangered Plants. Site accessed February 2010. URL = http://cnps.web.aplus.net/cgi-bin/inv/inventory.cgi.

Cook, L, L. Buffaloe. 1998. Delta agricultural diversion evaluation summary report, 1993-1995. Interagency Ecological Program Technical Report 61. Sacramento, CA: California Dept. of Water Resources.

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm (Version 04DEC98).

Culberson, Steven, Loren Bottorff, Mark Roberson, and Elizabeth Soderstrom. 2008. "Geophysical Setting and Consequences of Management in the Bay-Delta." The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

DFG (California Department of Fish and Game). 1995. Fish Species of Special Concern in California, Spring-run Chinook Salmon. Habitat Conservation Planning Branch. Available at: http://www.dfg.ca.gov/hcpb/species/ssc/sscfish/sprngrnchnok.htm.

DFG (California Department of Fish and Game). 2005. The Status of Rare, Threatened, and Endangered Plants and Animals in California 2000–2004. Sacramento, California.

DFG (California Department of Fish and Game). 2008. Ecosystem Restoration Program (ERP) Conservation Strategy for Stage 2 Implementation, Sacramento-San Joaquin Delta and Suisun Marsh and Bay Planning Area. Administrative Draft, Version 2.2, August 18, 2008. Sacramento, California. 149 pp.

Dill, William A, & Cordone, Almo J. (1997). History And Status of Introduced Fishes In California, 1871 – 1996. UC San Diego: Scripps Institution of Oceanography Library. Fish Bulletin 178. Retrieved from: http://www.escholarship.org/uc/item/5rm0h8qg

Dugdale, R. C., F. P. Wilkerson, V. E. Hogue, and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science. 73:17-29.

DWR (California Department of Water Resources . 1999. Suisun Marsh Monitoring Program Reference Guide. http://www.water.ca.gov/suisun/docs/SMSCGReferenceGuide_Version02.pdf

DWR (California Department of Water Resources (DWR). 2000. Suisun Marsh Levee Investigation Report. Chapter V – DWR Modeling Results – Hydrodynamics and Salinity Impacts of Suisun Marsh Levee Breaches Using DWRDSM1. Sacramento CA. http://www.water.ca.gov/suisun/modeling/chapterV.cfm#middle_column. Accessed on September 30, 2010.

DWR (California Department of Water Resources). 2005. Bulletin 250. Fish Passage Improvement. Available at: http://www.watershedrestoration.water.ca.gov/fishpassage/b250/content.html.

DWR (California Department of Water Resources). 2005. Sacramento-San Joaquin Delta Atlas. State of California Resources Agency, Sacramento, California. 121 pp.

DWR (California Department of Water Resources). 2007. Status and Trends of Delta Suisun Services. Public Review draft. March 2007. Prepared by URS Corporation.

DWR (California Department of Water Resources). 2009a. California's Groundwater: Bulletin 118. 17 Individual Basin Descriptions. Site accessed January through April 2009. URL = http://www.groundwater.water.ca.gov/bulletin118/basin_desc/index.cfm

England, A. S., J. A. Estep, and W. R. Holt. 1995. Nest-Site Selection and Reproductive Performance of Urban-Nesting Swainson's Hawks in the Central Valley of California. *Journal of Raptor Research* Volume 29: 179–186.

England, A. S., M. J. Bechard, and C. S. Houston. 1997. Swainson's Hawk (*Buteo swainsoni*). In: A. Poole and F. Gill (eds.), *Birds of North America*, No. 265. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C.

Estep, J. A. 1989. *Biology, Movements, and Habitat Relationships of the Swainson's Hawk in the Central Valley of California, 1986-87*. Nongame Bird and Mammal Section Report. California Department of Fish and Game, Sacramento, California.

Fairbridge 1980. The estuary: its definition and geodynamic cycle. Pages 1-35 in E. Olaussen and I. Cato, eds. Chemistry and geochemistry of estuaries. John Wiley, NY

Feyrer, F., T. Sommer, and W. Harrell. 2006. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: evidence from two adjacent engineered floodplains on the Sacramento River, California. North American Journal of Fisheries Management 26: 408-417.

Feyrer F., M.L. Nobriga, T R. Sommer. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Science. 64: 723-734.

Foe, C., A. Ballard and S. Fong. May 2010. DRAFT REPORT: Nutrient concentrations and biological effects in the Sacramento-San Joaquin Delta.

Fris, M. B. and R. W. DeHaven. 1993. A community-based Habitat Suitability Index model for Shaded Riverine Aquatic Cover, selected reaches of the Sacramento River system (draft). USDI, FWS, Sacramento Field Office, CA. 23 pp.

Ganju, N. K. and D. H. Schoellhamer. 2010. Decadal-timescale estuarine geomorphic change under future scenarios of climate and sediment supply. Estuaries and Coasts 33: 15-29.

Gilbert, G.K. 1917. Hydraulic mining debris in the Sierra Nevada. U.S. Geological Survey Professional Paper 105, 154 pp. As cited in Jaffe, B.E., R.E. Smith, and A.C. Foxgrover. 2007. Anthropogenic influence on sedimentation and intertidal mudflat change in San Pablo Bay, California: 1856 to1983. Estuarine, Coastal and Shelf Science 73: 175-187.Gilbert, P. M. IN PRESS. Long term changes in nutrient loading and stoichiometry and their relationships with changes in the food web and dominant pelagic fish species in the San Francisco Estuary, California. Reviews in Fisheries Science.

Good, T.P., R.S. Waples, and P. Adams (editors). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-66, 598 p.

Goodman, D. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. Canadian Journal of Fisheries and Aquatic Sciences 62:374-389.

Grimaldo L, Ross B, Sweetnam D. 1998. Preliminary results on the age and growth of delta smelt from different areas of the estuary using otolith microstructural analysis. IEP Newsletter 11(1):25-28. Available at: http://www.iep.ca.gov/newsletter.

Grimaldo, L. and Z. Hymanson. 1999. What is the impact of the introduced Brazilian waterweed Egeria densa to the Delta ecosystem? Interagency Ecological Program Newsletter. 12(1): 43-45.

Grimaldo, L.F., R.E. Miller, C.M. Peregrin, and Z.P. Hymanson. 2004. Spatial and Temporal Distribution of Native and Alien Ichthyoplankton in Three Habitat Types of the Sacramento-San Joaquin Delta, in Early Life History of Fishes in the San Francisco Estuary and Watershed, edited by F. Feyrer, L.R. Brown, R.L. Brown, and J.J. Orsi. Bethesda, MD: American Fisheries Society, Bethesda MD. pp. 81-96.

Hansen, E. C. 2007. Implementation of Priority 1 Recovery Tasks for the Giant Garter Snake (*Thamnophis gigas*) in Merced County, California. Report prepared for U.S. Fish and Wildlife Service pursuant to FWS Agreement No. 802706G120. April 15, 2007.

Hansen, G. E. 1986. *Status of the Giant Garter Snake* Thamnophis couchii gigas *(Fitch) in the Southern Sacramento Valley during 1986*. Final report for the California Department of Fish and Game, Standard Agreement No. C-1433.

Hansen, G. E., and J. M. Brode. 1980. Status of the Giant Garter Snake *Thamnophis couchii gigas* (Fitch). *Inland Fisheries Endangered Species Special Publication* Volume 80(5): 1–14. California Department of Fish and Game, Sacramento, California.

Healey, M.C. 1980. Utilization of the Nanaimo River Estuary by juvenile Chinook salmon, Oncorhynchus tshawytscha. U.S. Fisheries Bulletin. 77: 653-668.

Healey, Michael, Michael Dettinger, and Richard Norgaard. 2008. "Introduction: New Perspectives on Science and Policy in the Bay-Delta." The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

Healey, Michael. 2008. "Science and the Bay-Delta." The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

Herbold, B. and P. B. Moyle. 1989. The Ecology of the Sacramento-San Joaquin Delta: A Community Profile. U.S. Fish and Wildlife Service Report 85(7.22). Washington, D.C. 106 pp.

Herren, J. R., S. S. Kawasaki. 2001. Inventory of water diversions in four geographic areas in California's Central Valley. In: R.L. Brown, ed., Contributions to the Biology of Central Valley Salmonids. Volume. 2. California Fish and Game. Fish Bulletin 179: 343-355

Hickson, D., and T. Keeler-Wolf. 2007. Vegetation and Land Use Classification and Map of the Sacramento-San Joaquin River Delta. Prepared by Vegetation Classification and Mapping Program, California Department of Fish and Game, Sacramento, California. Prepared for Bay Delta Region, California Department of Fish and Game. Sacramento, California. February 2007.

Hunter, J. C., and G. A. J. Platenkamp. 2003. The Hunt for Red Sesbania: Biology, Spread, and Prospects for Control. CalEPPC News, California Invasive Plant Council. 11(2):4-6.

Ivey, G. Ornithologist. Correspondence with Todd Sloat; October 2004 and January 2005. Cited in Sacramento County Website 2009.

James, P. C. 1992. Urban-Nesting of Swainson's Hawks in Saskatchewan. *Condor* Volume 94: 773–774.

Jassby, A.D., J.E. Cloern, B.E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography. 47: 698-712

Jassby, A.D., J.E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and Freshwater Ecosystems. 10: 323-352.

Jassby, AD, Van Nieuwenhuyse, EE. 2006. Low dissolved oxygen in an estuarine channel (San Joaquin River, California): mechanisms and models based on long-term time series. San Francisco Estuary and Watershed Science 3: http//repositories.cdlib.org/jmie/sfews/vol3/iss2/art2.

Kattelmann, R. 1996. Hydrology and water resources. Pages 855-920 in: Sierra Nevada Ecosystem Project (SNEP): Final Report to Congress. Vol. II: Assessments and Scientific Basis for Management Options. Wildland Resources Center Report No. 37. University of California, Davis, CA.

Kimmerer,W. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science [online serial]. Volume 2, Issue 1 (February 2004), Article 1.

Kimmerer, W.J., J.J. Orsi. 1996. Changes in the zooplankton of the San Francisco Bay estuary since the introduction of the clam Potamocorbula amurensis. In: Hollibaugh, JT, editor. San Francisco Bay: The Ecosystem. San Francisco, CA: Pacific Division, American Association for the Advancement of Science. pp 403-424.

Kimmerer, Wim J.(2008). Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science, 6(2). Retrieved from: http://escholarship.org/uc/item/7v92h6fs

Kimmerer, Wim, Larry Brown, Steven Culberson, Peter Moyle, Matt Nobriga and Jan Thompson. 2008. "Aquatic Ecosystems." The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

Knudsen, E.E., C.R. Steward, D. MacDonald, J.E. Williams, D.E. Reiser. 1999. Sustainable fisheries management: Pacific salmon. CRC Press. 752 pp.

Kuivila, K.M., and Jennings, B.E., 2007, Input, flux, and persistence of six select pesticides in San Francisco Bay: International Journal of Environmental Analytical Chemistry, v. 87, no. 13, p. 897-911, Kuivila, Kathryn, and Michelle Hladick. 2008. Understanding the Occurrence and Transport of Current-Use Pesticides in the San Francisco Estuary Watershed. San Francisco Estuary and Watershed Science. 6 (3): Article2. http://escholarship.org/uc/item/06n8b36k. Accessed on October 1, 2010.

Lankford, T.E. and T.E. Targett. 1994. Suitability of estuarine nursery zones for juvenile weakfish (Cynoscion regalis): effects of temperature and salinity on feeding, growth and survival. Marine Biology 119:611-620.

Lehman P.W., J. Sevier, J. Giulianotti, and M. Johnson. 2004. Sources of oxygen demand in the lower San Joaquin River, California. Estuaries, 27, 405–418.

Lindley, S.T., M.S. Mohr. 2003. Modeling the effect of striped bass on the population viability of Sacramento River winter-run Chinook salmon. Fishery Bulletin. 101: 321-331.

Lindley, S.T., R. Schick, A. Agrawal, M. Goslin, T.E. Pearson, E. Mora, J.J. Anderson, B. May, S. Greene, C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, J.G. Williams. 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science [online serial]. Vol. 5, Issue 1 (February 2006) Article 4.

Littlefield, C. D., and G. L. Ivey. 2000. *Conservation Assessment for Greater Sandhill Cranes Wintering on the Cosumnes River Floodplain and Delta Regions of California*. The Nature Conservancy, Galt, California.

Lucas, L.V., D.M. Sereno, J.R. Burau, T.S. Shranga, C.B. Lopez, M.T. Stacey, K.V. Parchevsky, and V.P. Parchevsky. 2006. Intradaily variability of water quality in a shallow tidal lagoon: mechanisms and implications. Estuaries and Coasts 29:711-730.

Lund, Jay, Peter Moyle, Jeff Mount, William Fleenor, Ellen Hanak and Richard Howitt. 2007a. Salinity Variability and Improving Conditions for Desirable Organisms in the Delta and Suisun Marsh. Prepared for the Delta Vision Blue Ribbon Trask Force, Sacramento, California, May 31, 2007. University of California Davis. http://deltavision.ca.gov/BlueRibbonTaskForce/May2007/Item_3_Attachment_2.pdf

Lund, Jay, Ellen Hanak, William Fleenor, Richard Howitt, Jeffrey Mount, and Peter Moyle. 2007b. Envisioning Futures for the Sacramento-San Joaquin Delta. Public Policy Institute of California, San Francisco. http://www.ppic.org/content/pubs/report/R_207JLR.pdf

Luoma, S. 2007. Water quality issues. Presentation at CALFED Science Workshop: Science Related to an Isolated Facility. 8/22/2007.

Luoma, Samuel, Susan Anderson, Brian Bergamaschi, Lisa Holm, Cathy Ruhl, David Schoellhamer, and Robin Stewart. 2008. “Water Quality.” The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

Marine, KR, Cech, JJ, Jr. 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook salmon. North American Journal of Fisheries Management 24:198-210.

Marvin-DiPasquale, M., and Agee, J.L., 2003, Microbial mercury cycling in sediments of the San Francisco Bay-Delta: Estuaries, v. 26, p. 1517-1528.

McClure, W. F. 1925. Maps and Profiles to Accompany Sacramento Flood Control Project. Revised Plans. Submitted to the Reclamation Board.

McEwan, D.R. 2001. Central Valley Steelhead. In: R. Brown, ed., Contributions to the biology of Central Valley salmonids. California Department of Fish and Game, Fish Bulletin No. 179.

Meyer, J.H. 1979. A review of the literature on the value of estuarine and shoreline areas to juvenile salmonids in Puget Sound, Washington. U.S. Fish and Wildlife Service. Fisheries Assistance Office, Olympia, Washington.

Missildine, B., R. Peters, R. Piaskowski, R. Tabor. 2001. Habitat complexity, salmonid use, and predation of salmonids at the bioengineered revetment at the Maplewood Golf Course on the Cedar River, Washington. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Office, Lacey, Washington.

Monroe, M., P.R. Olafson, J.N. Collins, R.M. Grossinger, J. Haltiner, and C. Wilcox. 1999. Baylands Ecosystem Habitat Goals: A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency, San Francisco, CA and Regional Water Quality Control Board, Oakland, CA.

Moore, Johnnie, and Roy Shlemon. 2008. "Levee System Fragility." The State of Bay-Delta Science, 2008. Healey, Michael C., Michael D. Dettinger, and Richard B. Norgaard, eds. Sacramento, CA: CALFED Science Program.

Mount, J., R. Twiss, R. M. Adams. 2006. The Role of Science in the Delta Visioning Process: a report of the Delta Science Panel of the CALFED Science Program. http://science.calwater.ca.gov/pdf/CSP_delta_vision_process_Twiss_062306.pdf (August 2007).

Moyle, P.B., W.A. Bennett, W.E. Fleenor, and J.R. Lund. 2010. Habitat variability and complexity in the Upper San Francisco Estuary. Delta Solutions, Center for Watershed Sciences, University of California at Davis. http://deltasolutions.ucdavis.edu

Moyle, Peter B., William A. Bennett, William E. Fleenor, and Jay R. Lund. 2010. Habitat Variability and Complexity in the Upper San Francisco Estuary. Delta Solutions, Center for Watershed Sciences, University of California, Davis. Available at: http://deltasolutions.ucdavis.edu/pdf/WorkingPapers/HabitatVariabilityandComplexity-2010Draft.pdf

Moyle P.B., R.D. Baxter, T. Sommer, T. C. Foin, S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: A review. San Francisco Estuary and Watershed Science [online serial]. Volume 2, Issue 2 (May 2004), Article 3.

Moyle, P.B. 2002. Inland fishes of California, Revised and Expanded. University of California Press, Berkeley, CA. 517 pp.

Moyle, P.B., B. Herbold, D. E. Stevens, L. W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society. 121: 67-77.

Moyle, Peter B. 1973. Recent changes in the fish fauna of the San Joaquin River system. Cal-Neva Wildlife 1973: 60-63.

Myrick C.A., J.J. Cech Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum Technical Publication 01-1. Available at: http://www.cwemf.org/Pubs/TempReview.pdf.

NMFS (National Marine Fisheries Service). 1996. Factors for decline: a supplement to the notice of determination for west coast steelhead under the Endangered Species Act. National Marine Fisheries Service, Protected Resource Division, Portland OR and Long Beach CA.

NMFS (National Marine Fisheries Service). 2007. Federal recovery outline for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of California Central Valley steelhead. Accessed: May 2007. Available at: http://swr.nmfs.noaa.gov/recovery/Concurrence-2007_Recovery_Outline_for_ESU.pdf

Nobriga M. 2008. Aquatic habitat conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Nobriga M.L., F. Feyrer, R.D. Baxter, M. Chotkowski. 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies, and biomass. Estuaries. 28(5): 776-785.

Nobriga, M, T.R. Sommer, F. Feyrer, K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt (*Hypomesus transpacificus*). San Francisco Estuary and Watershed Science, 6: 1, Article 1.

Nobriga, M.L. 2002. Larval delta smelt diet composition and feeding incidence: environmental and ontogenic influences. California Fish and Game 88(4): 149-164.

OEHHA (California Office of Environmental Health Hazard Assessment). 2008. Microcystis: Toxic Blue-Green Algae. Sacramento, CA. http://oehha.ca.gov/ecotox/pdf/microfactsheet122408.pdf

Orr, Michelle, Stephen Crooks and Phillip B. Williams. 2003. Will Restored Tidal Marshes Be Sustainable? San Francisco Estuary and Watershed Science 1(1): Article 5. http://escholarship.org/uc/item/8hj3d20t. Accessed on September 29, 2010.

Patterson, L. 2005. *Giant Garter Snake Surveys for the In-Delta Storage Program Year and Summary Report*. California Department of Water Resources, Sacramento, California.

Patterson, L., and E. Hansen. 2002. *Giant Garter Snake Habitat Evaluations for the Delta Wetlands Islands*. Prepared for California Department of Water Resources, Sacramento, California. November 2002.

Peterson, MS. 2003. A conceptual view of environment-habitat-production linkages in tidal river estuaries. Reviews in Fisheries Science 11:291-313.

Poff, N.L., Olden, J.D., Merritt, D. M. and Pepin, D. M. 2007. Homogenization of regional river dynamics by dams and global diversity implications. Proceedings, National Academy of Sciences 104: 5704-5710.

Pogson, T. H., and S. M. Lindstedt. 1988. *Abundance, Distribution, and Habitat of Central Valley Population Greater Sandhill Cranes during Winter*. Prepared for U.S. Fish and Wildlife Service, Portland, Oregon.

Presser, T.S., and Luoma, S.N., 2006, Forecasting selenium discharges to the San Francisco Bay-Delta Estuary: ecological effects of a proposed San Luis Drain extension: U.S. Geological Survey Professional Paper 1646, 196 p. (http://pubs.usgs.gov/pp/p1646/)

Raleigh R. F., T. Hickman, R. C. Solomon, P. C. Nelson. 1984. Habitat suitability information: rainbow trout. US Department of the Interior, US Fish and Wildlife Service, Washington DC, FWS/OBS-82/10.60.

Resources Agency. 2007. Pelagic Fish Action Plan. 84 pp. Available at: http://www.water.ca.gov/deltainit/030507pod.pdf.

Ringgold, C. 1852. A series of charts, with sailing directions, embracing surveys of the Farallones, the entrance to the bay of San Francisco, bays of San Francisco and San Pablo, straits of Carquines [sic] and Suisun Bay, confluence of the deltic branches of the Sacramento and San Joaquin rivers, and the Sacramento River (with the middle fork) to the American River, including the cities of Sacramento and Boston, state of California. J. T. Towers, Washington, D.C. 48 pp.

Ruhl, CA, Schoellhamer, DH, Stumpf, RP, Lindsay, CL. 2001. Combined use of remote sensing and continuous monitoring to analyse the variability of suspended-sediment concentrations in San Francisco Bay, California. Estuarine, Coastal, and Shelf Science 53:801-812.

San Francisco Estuary Institute. 1998. EcoAtlas Baylands Maps. Oakland, CA. http://www.sfei.org/ecoatlas

San Francisco Estuary Institute (SFEI). 2010. The Pulse of the Estuary: Linking the Watersheds and the Bay. SFEI Contribution 613. San Francisco Estuary Institute, Oakland, CA.

San Francisco Estuary Project (SFEP). 1991. Status and Trends Report on Wetlands and Related Habitats in the San Francisco Estuary. Prepared by the Association of Bay Area Governments, Oakland, CA. December 1991.

Simenstad, C., J. Toft, H. Higgins, J. Cordell, M. Orr, P. Williams, L. Grimaldo, Z. Hymanson, and D. Reed. 2000. Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH). Report from the Wetland Ecosystem Team, University of Washington, Seattle, WA.

Skinner JE. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Water Projects Report No. 1. Sacramento (CA): California Department of Fish and Game. 226 p. Available at: http://www.estuaryarchive.org/archive/skinner_1962/.

Smalling, Kelly L., Orlando, James L., & Kuivila, Kathryn M.(2007). Occurrence of Pesticides in Water, Sediment, and Soil from the Yolo Bypass, California. San Francisco Estuary and Watershed Science, 5(1). Retrieved from: http://escholarship.org/uc/item/9716926g

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. *Fisheries* 32(6): 270–27.

Sommer, T.R., D. McEwan, R. Brown. 2001b. Factors affecting Chinook salmon spawning in the lower Feather River. California Department of Fish and Game, Fish Bulletin. 179: 269-297.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, W.J. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences. 58: 325-333.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California’s Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26: 6-16.

Sommer. T. 2007. The decline of pelagic fishes in the San Francisco Estuary: an update. Presented to the California State Water Resources Control Board, Sacramento, CA, March 22, 2007. Available at: www.waterrights.ca.gov/baydelta/docs/pelagicorganism/dwr_032207sommer.pdf.

Stevens, D.E. 1966. Distribution and food habits of American Shad (Alosa sapidissima) in the Sacramento-San Joaquin Delta. In: J.L. Turner, D.W. Kelley, eds., Ecological studies of the San Francisco Bay Estuary. California Fish and Game Bulletin No. 136. pp. 97-107

Stockton, Steven L., Director of Civil Works, U. S. Army Corps of Engineers, Washington, DC. Letter to Benjamin F. Carter, President of the Central Valley Flood Protection Board. April 2, 2010.

Sturtevant, W.C. 1983. Handbook of North American Indians, Volume 10. Government Printing Office. 868 pp.

Swaim, Karen. 2010. Personal communication. Principal, Swaim Biological Incorporated, Livermore, CA. Meeting with AECOM biologist Thomas Leeman. June 10, 2010.

Swanson, C. and J.J. Cech, Jr. 1995. Environmental tolerances and requirements of the delta smelt, Hypomesus transpacificus. Final Report. Davis, California. 77 pp.

Sweetnam DA, Baxter RD, Moyle PB. 2001. True smelts. In: California Department of Fish and Game, California Sea Grant Program. California's living marine resources: a status report. p 472-479.

Sweetnam DA. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85:22-27.

Swolgaard, C. A. 2003. Nesting Density and Habitat Use of Swainson's Hawk in a Vineyard Landscape in the Northern San Joaquin Valley, California. Master's thesis, California State University, Sacramento, Sacramento, California.

The Bay Institute. 1998. From the Sierra-to-the-Sea: the Ecological History of the San Francisco Bay-Delta Watershed. Novato, California.

Thompson, B., R. Hoenicke, J.A. Davis, A. Gunther. 2000. An overview of contaminant-related issues identified by monitoring in San Francisco Bay. Environmental Monitoring and Assessment. 64: 409-419.

Thompson, J. 2007. Clams – where, how and can we limit the damage. Presentation at the CALFED Science Program workshop: Defining a Variable Delta to Promote Estuarine Fish Habitat. June 11, 2007.

U. S. Geological Survey (USGS). 1999. Land Subsidence in the United States. U.S. Geological Survey, Circular 1182.

URS/JBA (URS Corporation and Jack R. Benjamin & Associates, Inc. (URS/JBA). 2008a. Delta Risk Management Strategy Phase 1: Technical Memorandum - Impact to Ecosystem (Final). Sacramento, CA.

URS/JBA (URS Corporation and Jack R. Benjamin & Associates, Inc. (URS/JBA). 2008b. Delta Risk Management Strategy Phase 1: Risk Analysis Report (Final). Sacramento, CA.

USACE (U. S. Army Corps of Engineers (USACE). 2007. Treatment of Vegetation within Local Flood-Damage-Reduction Systems. Draft Final White Paper. Prepared by CECW-CE. April 20, 2007. Washington, DC.

USACE (U. S. Army Corps of Engineers (USACE). 2009. Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures. Engineering Technical Letter No. 1110-2-571. 10 April 2009. Washington, DC.

USBR (United States Bureau of Reclamation). 2004. Long-term Central Valley Project and State Water Project Operations Criteria and Plan, Biological Assessment. Available at: http://www.usbr.gov/mp/cvo/ocap/OCAP_6_30_04.pdf.

USEPA (United States Environmental Protection Agency). 1999. 1999 Update of ambient water quality criteria for ammonia. Office of Water Report No. EPA-822-R-99-014. December. 153 pp.

USFWS (U. S. Fish and Wildlife Service). 1999. Draft Recovery Plan for the Giant Garter Snake. Snake (Thamnopsis gigas). U.S. Fish and Wildlife Service, Portland, OR.

USFWS (U.S. Fish and Wildlife Service) 2010. Records search of Federal Endangered and Threatened Species in plan area quadrangles. Accessed February 16, 2010. URL = http://www.fws.gov/sacramento/es/spp_lists/auto_list.cfm.

USFWS (U.S. Fish and Wildlife Service). 2006. *Giant Garter Snake (*Thamnophis gigas*) 5-Year Review: Summary and Evaluation*. Sacramento, California.

USFWS (United States Fish and Wildlife Service). 2001. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead trout. Red Bluff, California.

USFWS. 2004. Five year status review for the delta smelt. Sacramento, California. 50 pp.

Werner I, Anderson S, Larsen K, and Oram J. 2008. Chemical stressors conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Werner I., L. Deanovic, D. Markiewicz, M. Stillway, N. Offer, R. Connon, S. Brander, 2008. Final Report. Pelagic Organism Decline (POD): Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2006-2007. UC Davis – Aquatic Toxicology Laboratory, Davis, CA.

Werner, I. 2007. Pyrethroids in the water column – is there reason for concern? Seminar, University of California, Davis, November 8, 2007.

Weston, D. P., J. C. You, M. J. Lydy. 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. Environmental Science & Technology. 38(10): 2752-2759

Williams, J. G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science* 4 (3):Article 2.

Williamson, A. K., D. E. Prudic, and L. A. Swain. 1989. Ground-Water Flow in the Central Valley, California. USGS Professional Paper 1401-D.

Witham, C. W. 2003. *Tule Ranch Vernal Pools Botanical Resources Survey Report*. Yolo Basin Foundation. Davis, California.

Wright, S. A. and D. H. Schoellhamer. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. San Francisco Estuary and Watershed Science 2. Article 2.

Yoshiyama, R. M., F. W. Fisher, P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management. 18: 487-521.